

# Y-12

**OAK RIDGE  
Y-12  
PLANT**

**MARTIN MARIETTA**

## Y-12 CENTRAL FILES RECORD COPY

HUMAN HEALTH AND ENVIRONMENTAL RISK  
ASSESSMENT OF THE S-3 WASTE-MANAGEMENT  
AREA, Y-12 PLANT, OAK RIDGE, TENNESSEE

June 1989

Environmental Managment Department  
Health, Safety, Environment, and  
Accountability Division

Document Prepared by  
Geraghty & Miller, Inc.  
255 S. Tulane Avenue  
Oak Ridge, Tennessee 37830  
under  
Purchase Order 12Y-00206C

for

Oak Ridge Y-12 Plant  
Oak Ridge, Tennessee 37831  
operated by  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
for the  
U. S. DEPARTMENT OF ENERGY  
Under Contract No. DE-AC05-84OR21400

OPERATED BY  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
FOR THE UNITED STATES  
DEPARTMENT OF ENERGY

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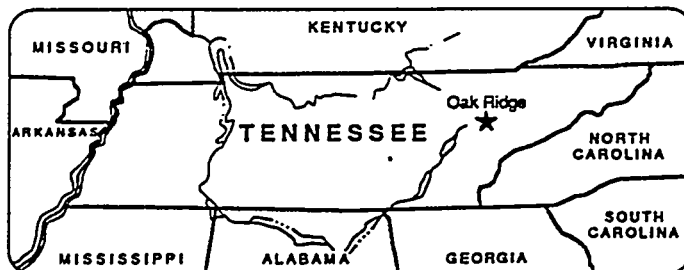
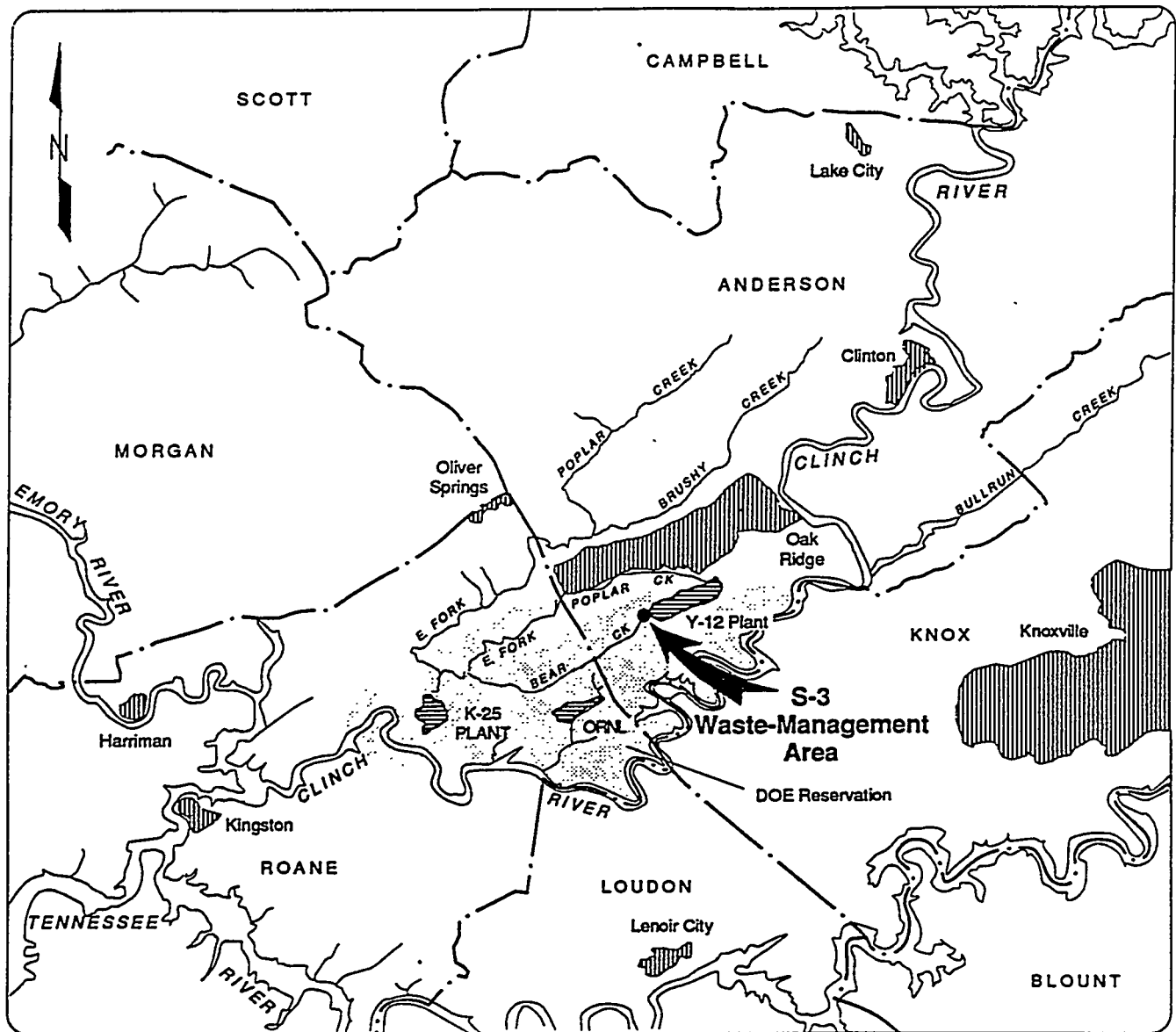
## 1.0 INTRODUCTION

The purpose of this risk assessment is to determine the potential public or environmental exposures and risks associated with constituents released to the environment as a result of operations at the S-3 Waste-Management Area (S-3 WMA). The S-3 WMA is located at the southwest end of the Y-12 Plant, but well within the DOE reservation (Figure 1-1). The S-3 WMA consists of one regulated unit, the S-3 Ponds Hazardous Waste Disposal Unit (S-3 Site), several non-regulated solid waste management units (SWMUs), and two sites regulated under the Department of Energy (DOE) Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) program (Figure 1-2).

The disposal of waste at the S-3 Site Hazardous Waste Disposal Unit was terminated in 1984; the ponds were stabilized and capped during 1988. A detailed history of the wastes disposed and the disposal operations is provided in the Post Closure Permit Application (PCPA) for the S-3 WMA (Geraghty & Miller, Inc., 1988a). This assessment will consider those constituents which have exhibited mobility in the environment as evidenced by their detection in the ground water. In this way, the risk assessment will focus on exposure to constituents released to the environment, and not occupational exposure.

Potential routes of exposure to constituents released from the ground water impacted by S-3 WMA are:

- surface water, through contact with and ingestion of waters of Bear Creek or East Fork Poplar Creek;
- sediments, through contact with and ingestion of sediments impacted by ground-water seepage;
- ground water, through contact with and ingestion of water pumped from the monitor wells; and
- fish, through ingestion of fish caught in Bear Creek or East Fork Poplar Creek.



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Figure 1-1. S-3 Waste-Management Area Regional Location Map



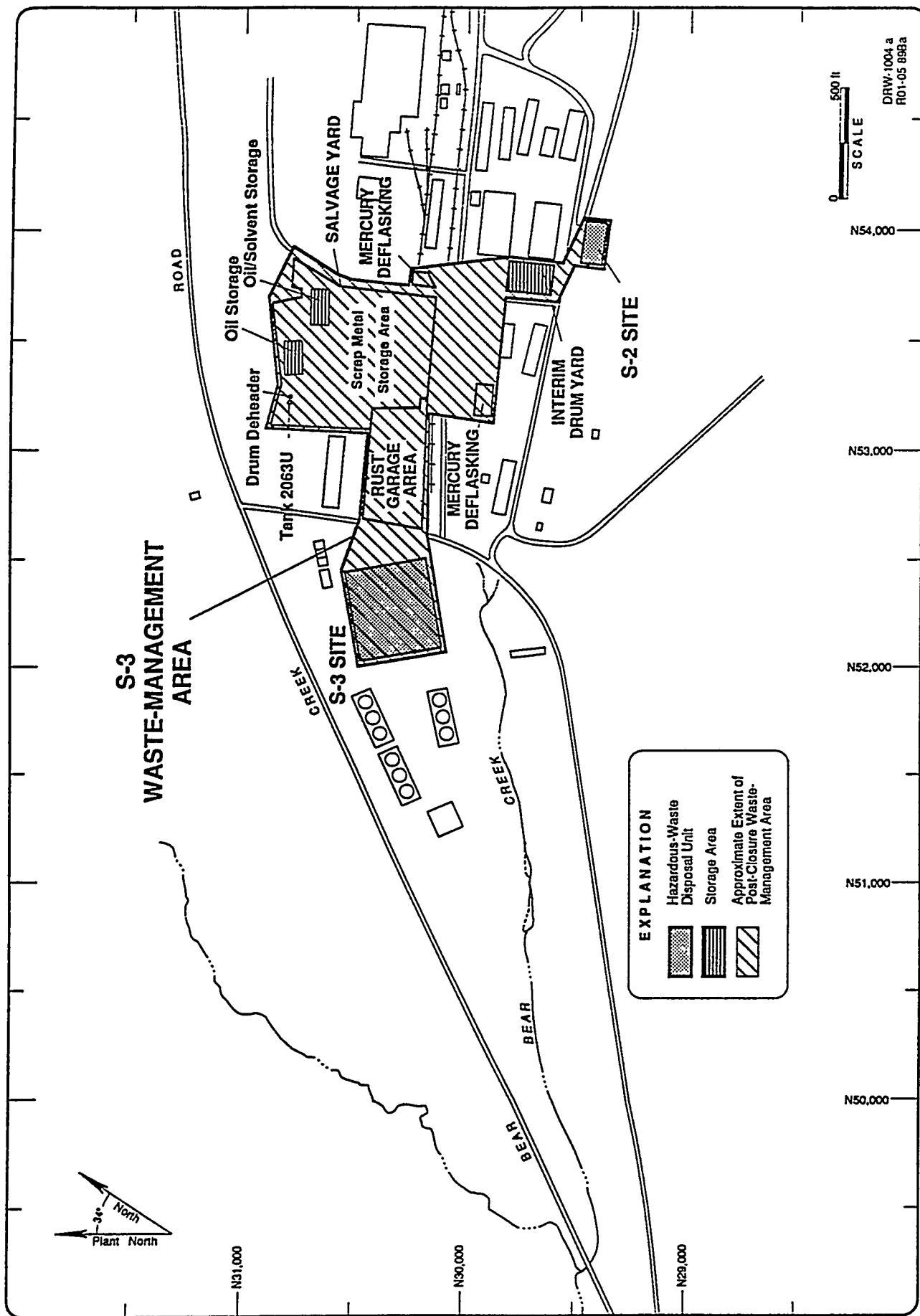


Figure 1-2. Components of the S-3 Waste-Management Area

A major factor pertaining to potential exposure at this site is the isolation of the facility from the public and the institutional controls on employee access within the Y-12 Plant.

This risk assessment report is divided into five major sections; 1) site characterization; 2) constituent characterization; 3) exposure assessment; 4) hazard evaluation; and 5) risk assessment.

The site characterization is a brief summary of applicable land-use, hydrogeology, and population data primarily obtained from the PCPA (Geraghty & Miller, Inc., 1988a).

In the Constituent Characterization Section, those constituents of greatest potential concern are identified as indicator chemicals based on toxicity and fate and transport properties. A more detailed assessment of the fate and transport properties has been prepared for the selected indicator chemicals.

The Exposure Assessment Section includes an assessment of constituent sources and transferences between the various media, and identification of exposure pathways. Exposure points and potentially exposed populations are identified for each pathway. Exposure dose levels for each of the exposure pathways are calculated based on site specific data and standardized conservative exposure parameters. The exposure doses are levels of daily intake of the constituents.

Toxicity data and dose/response relationships are discussed in the Hazard Assessment Section. Reference doses, cancer potency factors, and critical toxicity endpoints are identified for each of the indicator chemicals.

In the Risk Characterization Section, exposure doses calculated in the exposure section are evaluated in relation to the reference doses and unit cancer risks to ascribe a numerical value to the potential for adverse responses associated with possible exposure to the constituents. On the basis of comparison of the risk levels with current federal

guidelines for acceptable risk levels, a determination is made as to whether the exposure levels are acceptable. In addition, potential adverse effects to the environment are evaluated based on potential exposure levels and current federal guidelines.

## 2.0 SITE CHARACTERIZATION

The Y-12 plant is located in the southwest corner of Anderson County near the eastern extent of Bear Creek Valley, approximately 20 miles west of Knoxville and approximately 1.6 miles south of Oak Ridge. Bear Creek Valley is approximately one-mile wide, trends southwest to northeast, and extends approximately 12 miles. The valley is bounded on the south by Chestnut Ridge and on the north by Pine Ridge. The ridges rise approximately 300 feet (ft) above the valley floor and physically separate Bear Creek Valley from the downtown area of Oak Ridge and other public lands.

The Y-12 Plant is one of three industrial facilities built on 37,000 acres of federally owned land known as the DOE reservation (Figure 1-1). Approximately 80 percent of the DOE reservation is wooded. The land within the reservation serves as a buffer between the DOE facilities and the public. Restricted access to the DOE reservations enforced by DOE security personnel. Access to Bear Creek Valley is limited to one road and is controlled by DOE security measures.

The S-3 WMA is currently made up of one regulated unit, the S-3 Site, and four non-regulated solid waste management units, the S-2 Site, the Interim Drum Yard, the Salvage Yard, and the Rust Garage Area.

The S-3 WMA is located near a topographic divide which separates the headwaters of East Fork Poplar Creek to the northeast from the headwaters of Bear Creek to the southwest. Headwaters of East Fork Poplar Creek are an underground drainageway (storm sewer system) located adjacent to the Y-12 Plant (Rothschild, et al. 1984). The creek flows northeast for approximately 1.5 miles, where it turns north and flows toward Oak Ridge. On reaching Oak Ridge, the creek flows southwest along the axis of East Fork Valley, until it intersects Poplar Creek approximately 7 miles southwest of the S-3 Site.

Poplar Creek flows southwest through the K-25 Plant into the Clinch River (see Figure 1-1).

The upper reach of Bear Creek is located immediately south of the S-3 Site. Bear Creek flows southwest, away from the site, along the axis of Bear Creek Valley. Bear Creek becomes a perennial stream approximately 2 miles downstream of the headwaters. Approximately 5 miles downstream, the creek turns north and flows through Pine Ridge into East Fork Poplar Creek, which then joins with Poplar Creek 2 miles further downstream (see Figure 1-1).

The S-3 WMA is also located above a ground-water divide. North of the S-3 WMA, ground-water movement is to the south and southeast. South-southwest of the S-3 WMA ground-water movement is toward the southeast, while south-southeast of the S-3 WMA ground-water movement is toward the northeast (Geraghty & Miller, Inc., 1988a). The direction of ground water flow is along the Bear Creek Valley axis.

The hydrogeological system beneath the S-3 WMA can be divided into the upper unconsolidated zone, and the lower bedrock zone. The bedrock zone is composed of the six formations of the Conasauga Group. The S-3 Site, Rust Garage, and Mercury Deflasking Areas are underlain by the Nolichucky Shale; the Salvage Yard is underlain by the Maryville Limestone and Nolichucky Shale; the Interim Drum Yard lies near the contact between Nolichucky Shale and Maynardville Limestone; and the S-2 Site is directly underlain by the Maynardville Limestone. Flow in the shale and limestone is closely related to bedding planes, joints, fractures, and solution cavities. Both the unconsolidated zone and the bedrock zone of the shale units have relatively low water-transmitting capacity. Flow perpendicular to the bedding is retarded by the low permeability of the shale and is largely limited to areas where joints or fractures cut across bedding.

The rate of ground-water flow in the unconsolidated material has been calculated to be approximately 100 feet per year (ft/yr). Ground-water flow rates in the Conasauga Group (shales and limestones) are approximately 160 ft/yr (Geraghty & Miller, Inc., 1988a).

Population figures for residential areas and companies or facilities within 5 kilometers of the S-3 WMA identify the City of Oak Ridge and the Y-12 Plant as the largest population centers. The population of the City of Oak Ridge is 27,699 (1984 census) and the Y-12 Plant employs 7,133 workers. Other small facilities not located on the DOE reservation that were identified in the survey employ a total of 337 workers (Geraghty & Miller, Inc., 1988a). Of the Y-12 Plant employees, only a very small percentage are engaged in waste management, facility engineering, or research for which frequent access to either Bear Creek or East Fork Poplar Creek is anticipated.

The S-3 WMA is completely contained within the larger boundaries of the Y-12 Plant and the Oak Ridge DOE reservation. Potential for direct access by the general public is unlikely now, or at any time in the foreseeable future. The ground water impacted by waste constituents from the S-3 WMA discharges to Bear Creek and East Fork Poplar Creek within the confines of the DOE reservation. There are no ground-water wells beyond the DOE reservation that might intercept the impacted ground water now or planned in the future, based on the ground-water flow system. Thus, employees of the DOE facilities are the most likely exposed populations, and only a very small percentage of these employees are expected to access either Bear Creek or East Fork Poplar Creek.

### 3.0 CONSTITUENT CHARACTERIZATION

Waste constituents released from the S-3 WMA have been detected in the ground water, surface water, and sediments. Constituent concentrations used to assess potential hazards are associated with conditions following neutralization of the S-3 Ponds.

Ground-water quality at the S-3 WMA was characterized based on three sets of analytical data; (1) Appendix IX analytical results for ground-water samples collected in November and December 1987 from selected wells in the S-3 WMA, (2) data presented in the 1987 Ground-Water Quality Assessment Report for the S-3 Site (Geraghty & Miller, Inc., 1988b) and, (3) data provided by characterization monitoring in 1987 at the SWMUs included in the S-3 WMA. The level of quality control maintained and documented in the collection and analysis of these samples is sufficient to provide a high level-of-confidence in the results. Constituents that were detected in the ground water at concentrations exceeding background concentrations and drinking water standards or criteria were compiled (Table 3-1).

Concentrations of constituents seeping from the ground water to the headwaters of Bear Creek were characterized by weekly samples collected at Bear Creek kilometer (BCK) 12.4, which is directly south of the S-3 Site (Figure 3-1). Maximum and average concentrations detected in Bear Creek based upon the analytical results of those samples are listed in Table 3-2.

Water samples from East Fork Poplar Creek were collected at the influent to New Hope Pond. East Fork Poplar Creek receives approximately 8 million gallons of process and cooling water per day from Y-12 Plant operations. Past Y-12 Plant operations resulted in the release of metals to East Fork Poplar Creek, and elevated concentrations of some metals (i.e. mercury) remain in the sediments of East Fork Poplar Creek and are slowly released to the waters. As a conservative estimate of present and future hazards associated

Table 3-1. Constituents Detected in Ground Water Associated with the S-3 Waste-Management Area

Constituent	Maximum Concentration <sup>a</sup>	Average <sup>b</sup> Concentration	Ground-Water <sup>c</sup> Background Concentration	Standard or Criteria	Source
<b>Inorganics</b>					
Arsenic	0.073	0.0038	<0.005	0.050	d
Barium	425	47	0.28	1.0	d
Beryllium	0.31	0.015	<0.0003	0.0000068	e
Cadmium	7.84	0.099	<0.002	0.010	d
Chromium	0.61	0.023	<0.01	0.050	d
Cobalt	2.8	0.22	<0.005	0.0007	f
Copper	180	0.093	<0.004	1.0	g
Lead	0.62	0.022	<0.01	0.050	d
Mercury	0.176	0.0075	<0.0002	0.002	d
Nickel	40	2.08	<0.01	0.0134	e
Nitrate (as N)	16,900	2,180	<0.11	10.0	d
Uranium	75.7	2.57	<0.001		
Vanadium	0.037	0.037	<0.005	0.007	f
Zinc	11	0.50	0.019	5.0	g
<b>Organics</b>					
Acetone	0.60	0.0199	NA	4.0	h
Benzene	0.074	0.0023	NA	0.005	d
Bromoform	0.019	0.0004	NA	0.10	d
2-Butanone	0.096	0.0034	NA	0.17	i
Carbon Tetrachloride	0.99	0.0024	NA	0.005	d
1,1-Dichloroethene	0.77	0.0002	NA	0.007	d
trans-1,2-Dichloroethene	0.63	0.0039	NA	0.070	j
Methylene Chloride	0.22	0.0074	NA	0.350	i
Methyl Isobutyl Ketone	0.03	0.0009	NA	2.0	h
1,1,2,2-Tetrachloroethane	0.027	—	NA	0.00017	e
Tetrachloroethene	7.2	0.271	NA	0.0008	e
Toluene	0.011	0.00093	NA	14.3	e
1,1,1-Trichloroethane	2.2	0.0015	NA	0.20	d
Trichloroethene	2.1	0.033	NA	0.005	d

NOTE: All concentrations reported in milligrams per liter (mg/L).

SOURCE: <sup>a</sup> Concentrations from 1985-1987 Water-Quality Data (Geraghty & Miller 1988b).<sup>b</sup> Calculated from 1985-1987 Water Quality Data (Geraghty & Miller 1988b)<sup>c</sup> Concentration detected in well GW-115 in November, 1987.<sup>d</sup> Federal primary drinking-water standard; 40 CFR 141.62.<sup>e</sup> Federal Water-Quality Criteria (FWQC) For water and fish ingestion (USEPA 1986a).<sup>f</sup> Suggested ambient goal (USEPA 1977).<sup>g</sup> Federal secondary drinking-water standard; 40 CFR 143.3.<sup>h</sup> Reference Dose Limit (USEPA 1987a).<sup>i</sup> Office of Drinking Water Lifetime Health Advisory (USEPA 1987b).<sup>j</sup> Proposed Federal Maximum contaminant level goal; Federal Register, November 13, 1985.

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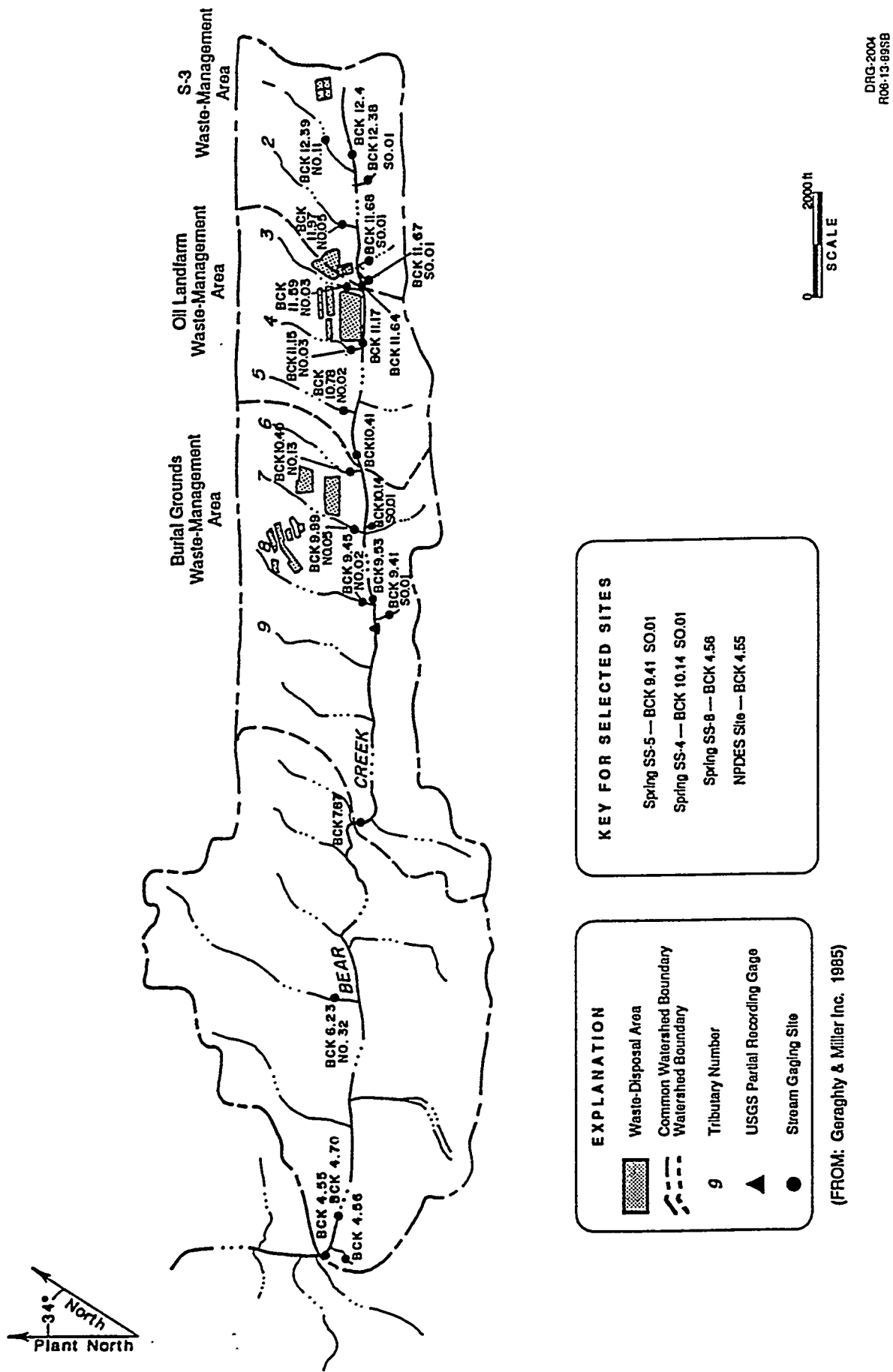


Figure 3-1. Bear Creek Valley Watershed and Location of Stream Gaging Sites

Table 3-2. Constituents Detected in Bear Creek and New Hope Pond Potentially Associated with the S-3 Waste-Management Area

Constituent	Bear Creek		East Fork Poplar Creek		Background Concentration	FWQC
	Maximum Concentration	Average Concentration	Maximum Concentration	Average Concentration		
<b>Inorganics</b>						
Aluminum	20.6	<1.01	4.64	0.59	0.60	—
Arsenic	<0.04	<0.04	<0.04	<0.04	—	0.048
Barium	0.195	0.076	0.468	0.053	0.044	50
Beryllium	0.001	<0.0002	0.0002	<0.0001	—	0.0053
Cadmium	0.017	<0.006	<0.003	<0.003	0.004	0.0011
Chromium	0.014	<0.006	0.026	<0.007	—	0.011
Cobalt	0.008	<0.006	0.004	<0.002	—	—
Copper	0.025	<0.004	0.29	0.012	—	0.012
Lead	0.020	<0.02	0.02	<0.02	—	0.0032
Mercury	0.002	<0.0004	0.22	0.0082	0.1	0.000012
Nickel	0.029	<0.008	0.36	<0.009	0.01	0.160
Nitrate (as N)	600	198	8	3.1	0.6	—
Uranium	1.69	0.969	0.029	0.007	2.0	—
Vanadium	0.018	<0.004	0.011	<0.005	—	—
Zinc	0.097	<0.009	0.246	0.094	0.014	0.11
<b>Organics</b>						
Chloroform	0.080	<0.01	—	—	—	1.24
Methylene Chloride	0.048	<0.01	—	—	—	11
Tetrachloroethene	<0.01	<0.01	—	—	—	0.84
1,1,1-Trichloroethane	<0.01	<0.01	—	—	—	—
Trichloroethene	<0.01	<0.01	—	—	—	21.9
PCB	0.0006	<0.0005	—	—	—	0.000014

NOTE: All concentrations reported in milligrams per liter (mg/L).

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SOURCE: a 1987 weekly sampling at Bear Creek (BCK 12.4) (Martin Marietta Energy Systems 1988).

b 1987 weekly sampling at East Fork Poplar Creek at New Hope Pond Influent (Martin Marietta Energy Systems 1988).

c Unimpacted local Surface-Water Quality (Grassy Creek) (Loar 1985).

d Federal Water Quality Criteria for fresh-water aquatic life (USEPA 1986a).

with seepage of plume constituents to East Fork Poplar Creek, the concentrations reported in weekly samples collected in 1987 are considered to represent constituents released from the S-3 WMA. Maximum and average concentrations are listed in Table 3-2.

Sediment samples from East Fork Poplar Creek and Bear Creek were collected in 1984 and 1985 (Tennessee Valley Authority, 1986). Sediment samples were collected from 418 locations in East Fork Poplar Creek and 19 locations in Bear Creek, and the maximum and average concentrations are listed in Table 3-3.

Table 3-3. Constituents Detected in Bear Creek and East Fork Poplar Creek Sediments and Fish

Constituent	East Fork Poplar Creek			Bear Creek		
	Sediments		Fish	Sediments		Fish
	Maximum	Average		Maximum	Average	
Arsenic	14	7.1	ND	ND	ND	ND
Cadmium	8.5	1.8	0.014	10	4.6	0.026
Lead	170	80	ND	ND	ND	ND
Mercury	1800	77	1.4	3.9	0.63	0.56
Nickel	81	39	ND	200	89	ND
Silver	45	8	ND	ND	ND	ND
Uranium	ND	ND	ND	200	42	ND
Zirconium	590	448	ND	590	483	ND
Total PCBs	6	1.6	ND	1.4	1.0	ND

NOTE: All concentrations reported in milligrams per liter (mg/L).

SOURCE: Tennessee Valley Authority 1986

ND - Not Detected

### 3.1 INDICATOR CHEMICAL SELECTION

The indicator chemical selection procedure is designed to identify the "highest risk" chemicals at the site, thereby focusing the risk assessment on the chemicals of greatest potential concern. An important factor used to rank chemicals in the selection process is the potential hazard, which is a function of concentrations detected at the site and the inherent toxicity of the compound. Additional factors to be considered are physical and chemical

parameters related to environmental mobility and persistence. The selection procedure is described in detail in the U.S. Environmental Protection Agency Superfund Public Health Evaluation Manual (SPHEM) (U.S. Environmental Protection Agency, 1986b).

The maximum concentrations were used to initially identify those constituents which will be evaluated. Fourteen inorganic constituents and 14 organic constituents were ranked according to potential hazard. Potential hazards for noncarcinogenic constituents were determined by multiplying the average ground water concentration by a toxicity constant derived from the minimum effective dose (MED) for chronic effects and a severity of effect factor (U.S. Environmental Protection Agency, 1986b). Toxicity constants for potential carcinogens are based on the dose at which a 10 percent incremental carcinogenic response had been observed (ED50). Toxicity constants used in the selection process were obtained from the SPHEM (U.S. Environmental Protection Agency, 1986b). The results of ranking the potential noncarcinogenic and carcinogenic hazards are listed in Table 3-4 with lower numbers indicating higher rank and greater hazard. Based on the ranking in Table 3-4, the inorganic constituents detected at the S-3 WMA exhibit a greater toxicity hazard than the organic constituents. Only trichloroethene appears in the top 10 constituents, and tetrachloroethene and carbon tetrachloride are ranked 12 and 13 respectively. The inorganic constituents of highest noncarcinogenic toxicity ranking are barium, uranium, nickel, cadmium, and mercury. Arsenic is ranked number 6; however, the average concentration is below the federal primary drinking water standard (50 ug/L), indicating that constituents with a lower rank than arsenic are probably not as great a toxicity concern.

Arsenic was ranked number one in the selection process for the potential carcinogens (Table 3-4). The organic suspect carcinogens scored below arsenic. Ranking of the organic potential carcinogens from higher score to lower was carbon tetrachloride, tetrachloroethene, trichloroethene, 1,1-dichloroethene, and benzene. As indicated in the

Table 3-4. Indicator Chemical Selection Ranking of Constituents Detected in Ground Water

Constituent	C (mg/L)	Non-carcinogenic			Carcinogenic		
		wTN	CT	Rank	wTC	CT	Rank
Inorganics							
Arsenic	0.0038	18.0	0.068	6	4.07	0.015	1
Barium	47	4.08	190	1	—	—	—
Beryllium	0.015	—	—	—	—	—	—
Cadmium	0.099	4.45	0.44	4	—	—	—
Chromium	0.023	0.0188	0.00027	15	—	—	—
Cobalt	0.22	—	—	—	—	—	—
Copper	0.093	0.714	0.066	7	—	—	—
Lead	0.022	0.893	0.020	10	—	—	—
Mercury	0.0075	18.4	0.138	5	—	—	—
Nickel	2.8	4.26	8.9	3	—	—	—
Nitrate (as N)	2,180	—	—	—	—	—	—
Uranium	2.57	7.06	18.1	2	—	—	—
Vanadium	0.037	0.143	0.0053	11	—	—	—
Zinc	0.50	0.107	0.054	8	—	—	—
Organics							
Acetone	0.0199	—	—	—	—	—	—
Benzene	0.0023	0.117	0.00027	16	0.0771	0.000018	6
Bromoform	0.0004	1.82	0.00073	14	—	—	—
2-Butanone	0.0034	0.00775	0.000026	19	—	—	—
Carbon Tetrachloride	0.0024	0.317	0.00076	13	1.88	0.0045	2
1,1-Dichloroethene	0.0002	0.371	0.000074	18	0.123	0.000025	5
trans-1,2-Dichloroethene	0.0039	0.0529	0.00021	17	—	—	—
Methylene Chloride	0.0074	0.00092	0.0000068	20	—	—	—
Methyl Isobutyl Ketone	0.0009	—	—	—	—	—	—
1,1,2,2-Tetrachloroethane	—	0.455	—	—	—	—	—
Tetrachloroethene	0.2711	0.00962	0.0026	12	0.00886	0.0024	3
Toluene	0.00093	0.0052	0.0000048	21	—	—	—
1,1,1-Trichloroethane	0.0015	0.000733	0.0000011	22	—	—	—
Trichloroethene	0.033	1.05	0.035	9	0.000429	0.00014	4

C = Average constituent concentration detected in ground water.

wTN = Constituent-specific toxicity constant for noncarcinogenic effects in water.

CT = Calculated site-specific indicator score (C x wTN).

wTC = Constituent-specific toxicity constant for carcinogenic effects in water.

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noncarcinogenic ranking the average arsenic concentration used in the ranking process is below the federal primary drinking-water standard. Therefore, even though arsenic was ranked number one in the process, exposure to arsenic at concentrations below the federal standard would be acceptable. From a regulatory perspective the hazards associated with the average reported arsenic concentrations are acceptable. Tetrachloroethene and trichloroethene are the only potential carcinogens that have average reported concentrations exceeding drinking-water standards or criteria. Although they are ranked 3 and 4 in the indicator chemical selection process, from a regulatory perspective they are the only potential carcinogens representing an unacceptable drinking-water hazard based on the average concentrations.

Indicator scores for constituent concentrations detected in the surface water and sediments are listed in Tables 3-5 and 3-6, respectively. Uranium, barium, and mercury are the top three ranking constituents in the surface water based on the highest average concentration from either Bear Creek or East Fork Poplar Creek (Table 3-5). Mercury, nickel, and uranium are the top three ranking constituents detected in the sediments of Bear Creek or East Fork Poplar Creek (Table 3-6).

Nitrate is the principal ground-water contaminant at the S-3 Site (Geraghty & Miller, Inc., 1988a). Its extent is believed to mark the maximum migration of all contaminants originating from the ponds because it occurs in ground water as a stable, negatively charged ion which may travel uninhibited through the ground-water system for long distances. Nitrate is not listed as a hazardous constituent by the Environmental Protection Agency (EPA), and there is no toxicity constant for nitrate in the SPHEM (U.S. Environmental Protection Agency, 1986b). However, there is a federal drinking-water standard of 10 mg/L of nitrate (as N), and ground water containing more than 10 mg/L of nitrate (as N) extends at least 1,500 ft northeast and southwest of the S-3 Site and in a narrow belt paralleling Bear Creek for approximately 3,900 ft downstream of the site.

Table 3-5. Indicator Chemical Selection Ranking of Constituents  
Detected in Surface Water

Constituent	C	wTn	CT	Rank
<b>Inorganics</b>				
Aluminum	0.59	—	—	
Arsenic	<0.04	18	—	
Barium	0.076	4.080	0.31	2
Beryllium	<0.0002	—	—	
Cadmium	0.006	4.45	—	
Chromium	<0.007	0.0118	—	
Cobalt	<0.006	—	—	
Copper	0.012	0.714	0.0086	5
Lead	<0.002	0.893	—	
Mercury	<0.0082	18.4	0.15	3
Nickel	<0.009	4.26	—	
Nitrate (as N)	198	—	—	
Uranium	0.969	7.06	6.8	1
Vanadium	<0.005	0.143	—	
Zinc	0.094	0.107	0.010	4

C = Average concentration (mg/L) of weekly samples from Bear Creek at BCK 12.4 collected in 1987 (Martin Marietta Energy Systems 1988)

wTN = Constituent-specific toxicity constant for noncarcinogenic effects in water (USEPA 1986b)

CT = Calculated site-specific indicator score (CT = C x wTn)

Table 3-6. Indicator Chemical Selection Ranking of Constituents  
Detected in Bear Creek or East Fork Poplar Creek Sediments

Constituent	C	sTn	CT	Rank
<b>Inorganics</b>				
Arsenic	7.1	$9.0 \times 10^{-4}$	0.0064	5
Cadmium	4.6	$2.23 \times 10^{-4}$	0.0010	7
Lead	80	$4.46 \times 10^{-5}$	0.0036	6
Mercury	77	$9.21 \times 10^{-4}$	0.071	1
Nickel	89	$2.13 \times 10^{-4}$	0.019	2
Silver	8	$1.0 \times 10^{-3}$	0.0080	4
Uranium	42	$3.53 \times 10^{-4}$	0.015	3
Zirconium	483	—	—	
Total PCBs	1.6	—	—	

C = Concentrations (mg/L) detected in Bear Creek sediments collected in 1984 and 1985 (TVA 1986)

sTn = Constituent-specific toxicity constant for noncarcinogenic effects in soils (USEPA 1986b)

CT = Calculated site-specific indicators score (CT = C x sTn)

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Given the prevalence of concentrations exceeding drinking-water standards and the relatively high mobility, nitrate is chosen as one of the indicator chemicals for the S-3 WMA.

The other factors considered in determining the indicator chemicals are the mobility and persistence of the constituents in the environment. Five important chemical properties related to exposure potential are the water solubility, vapor pressure, Henry's Law constant, organic carbon partition coefficient, and half-lives (U.S. Environmental Protection Agency, 1986b). Indicator chemicals selected should cover the range of values reported for these properties. Values for these properties in addition to molecular weight, specific gravity, the log of the octanol/water partition coefficient, and the fish bioconcentration factor (BCF) are reported in Table 3-7.

Based on the toxicity ranking and the environmental fate properties, those constituents most representative of the release of chemicals to the environment at the S-3 WMA are barium, uranium, nickel, cadmium, mercury, tetrachloroethene, trichloroethene, and nitrate (Tables 3-4 to 3-6). These eight constituents are the most prevalent and potentially toxic of the constituents reported in the ground water. The eight indicator chemicals are representative of the range of potential environmental mobilities and persistence (Table 3-7). Thus, these eight constituents exhibit the highest potential risks associated with chemicals released from the S-3 WMA.

### 3.2 FATE AND TRANSPORT

Mobility and stability of constituents released to the environment are a function of a large number of physical and chemical processes which are dependent in part on the characteristics of the media and in part on the characteristics of the chemical. Solubility and the potential to be adsorbed by organic or inorganic material will control the extent to which



Table 3-7. Physical and Chemical Properties of Constituents Reported at the S-3 Waste-Management Area

Constituent	Molecular Weight (g/mole)	Water Solubility (mg/L)*	Specific Gravity	Vapor Pressure (mm Hg)	Henry's Law Constant (atm-m <sup>3</sup> /mole)	K <sub>oc</sub> (mL/g)	Log K <sub>ow</sub>	Fish BCF (L/kg)	Water T 1/2 (days)
Arsenic	75	—	5.72	—	—	—	—	44	NA
Barium	137	—	3.5	—	—	—	—	—	NA
Beryllium	9	—	1.85	—	—	—	—	19	NA
Cadmium	112	—	8.642	—	—	—	—	81	NA
Chromium	52	—	7.2	—	—	—	—	16	NA
Cobalt	59	—	8.9	—	—	—	—	—	NA
Copper	64	—	8.92	—	—	—	—	200	NA
Lead	207	—	11.35	—	—	—	—	49.0	NA
Mercury	201	—	13.59	0.002	—	—	—	5500	NA
Nickel	59	—	8.902	—	—	—	—	47	NA
Nitrate (as N)	62	—	—	—	—	—	—	—	NA
Uranium	238	—	19.05	—	—	—	—	330	NA
Vanadium	51	—	5.96	—	—	—	—	—	NA
Zinc	65	—	7.133	—	—	—	—	47	NA
Acetone	58	1,000,000	0.7908	270	2.06 E-05	2.2	-0.24	0.99	—
Benzene	78	1,750	0.8787	95.2	5.59 E-03	83	2.12	5.2	1.0 - 6.0
Bromoform	253	3,010	2.89	5.0	5.52 E-04	116	2.40	3.75	0.3 - 30
2-Butanone	72	268,000	0.8054	77.5	2.74 E-05	4.5	0.26	0	10
Carbon Tetrachloride	154	757	1.59	90	2.41 E-02	110	2.64	19	0.3 - 300
1,1-Dichloroethene	97	2,250	1.218	600	3.40 E-02	65	1.84	5.6	1.0 - 6.0
trans-1,2-Dichloroethene	97	6,300	1.256	324	6.56 E-03	59	0.48	1.6	1.0 - 30
Methylene Chloride	85	20,000	1.335	362	2.03 E-03	8.8	1.30	5.0	1.2 - 5.8
Methyl Isobutyl Ketone	100	19,000	0.8017	6.0	4.16 E-05	21.7	1.55	5.3	—
1,1,2,2-Tetrachloroethane	168	2,900	1.626	5.0	3.81 E-04	118	2.39	42	0.04
Tetrachloroethene	166	150	1.623	17.8	2.59 E-02	364	2.60	31	1.0 - 3.0
Toluene	92	535	0.8669	28.1	6.37 E-03	300	2.73	10.7	0.17
1,1,1-Trichloroethane	133	1,500	1.35	123	1.44 E-02	152	2.50	5.6	0.14 - 7.0
Trichloroethene	131	1,100	1.462	57.9	9.1 E-03	126	2.38	10.6	1.0 - 90

K<sub>oc</sub>: Organic Carbon Partition CoefficientK<sub>ow</sub>: Octanol/Water Partition Coefficient

BCF: Bioconcentration Factor

T 1/2: Half Life

NA - Not Applicable

\* Values may vary depending on compound, pH, temperature, and redox potential

SOURCES: U.S. Environmental Protection Agency 1986b

Verschuren 1977

Weast 1981

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a chemical will be transported within a solution phase. Volatility determines the extent to which material will dissipate into the atmosphere.

The ultimate behavior of a constituent is the result of the equilibrium established among the various processes which operate on the constituents in the environment. The chemical equilibrium is dynamic, and is dependent on the physical and chemical characteristics of the constituents and the physical and chemical characteristics of the environmental system. Physical and chemical parameters for the indicator chemicals are listed in Table 3-7. The following sections discuss the transport and fate characteristics of the indicator chemicals.

### 3.2.1 Barium

Barium is a naturally occurring metal found in many types of rock. Limestone, sandstones and soils in the eastern U.S. contain 300 to 500 mg/kg of barium (Federal Register Vol. 50, No. 219). The range of natural barium concentrations in the soils of the conterminous U.S. is reported to be 10 to 1,500 mg/kg with an average background soil concentration of 580 mg/kg (U.S. Geological Survey, 1984).

Barium is a reactive metal that is not found free in the environment but exists as a number of salts. The chief barium mineral found in nature is barite ( $\text{BaSO}_4$ ). The mineral forms of barium are relatively insoluble. Barium occurs at low concentrations in most surface and ground waters with reported levels of less than 340 ug/L (U.S. Environmental Protection Agency, 1979).

Most foods also contain barium as a low-level contaminant. Food is the major source of barium exposure (Beliles, 1979).

Many of the salts of barium are soluble in both water and acid. However, barium ions are rapidly precipitated or removed from solution by sorption and sedimentation

(McKee and Wolf, 1963). Soluble barium concentrations would have to exceed 50 mg/L in fresh or marine waters to be toxic to the aquatic organisms, however, no aquatic criteria has been set for barium because most natural waters have sufficient sulfate and carbonate to precipitate the barium out of solution as a virtually insoluble, non-toxic compound (U.S. Environmental Protection Agency, 1986a).

The biological half-life of barium is short (less than 24 hours) (Beliles, 1979). Soluble barium compounds that are absorbed are transported by the plasma and excreted via the feces. Plants accumulate barium from the soil; however, barium is not biomagnified in the food chain.

The major transport mechanism of barium at the S-3 WMA is leaching to and transport in the ground water of dissociated barium ions. The mobility of barium will decrease as barium is precipitated out of solution by the carbonate and sulfate in the ground-water and surface-water systems.

### 3.2.2 Cadmium

In the natural environment cadmium is a rare metal, occurring in crustal rocks at an average concentration of 0.15 mg/kg. The average shale contains approximately 0.3 mg/kg cadmium. Most natural occurrences of cadmium are associated with zinc-sulfide ore deposits and carbonate-fluoride-barite-sulfide mineralization (Krauskopf, 1979).

Cadmium is generally present in surface and ground waters as a divalent cation. However, cadmium will form stable complexes in solution if sufficient concentrations of complexing ligands are available. The bicarbonate-metal complex is the most prevalent complex to form in fresh waters of neutral pH and normal oxidizing conditions. As the pH rises, the formation of hydroxide complexes is predicted. If the concentrations of the hydroxide or carbonate ligands become great enough, cadmium will precipitate as a

crystalline solid with either of the anions. Cadmium concentrations in waters that are anoxic and have sulfur present in the reduced oxidation state (-II) will cause cadmium to precipitate from solution as a crystalline sulfide (Hem, 1972; U.S. Environmental Protection Agency, 1979).

The concentration of cadmium in most surface and ground waters is well below the concentration limits predicted from solubility constraints. Cation exchange and adsorption reactions are thought to be at least partially responsible for the removal of cadmium below solubility limits. It is not known which substrates (clays, amorphous aluminum, iron, and manganese solids, or organic material) are the most efficient or favored for adsorption reactions. Studies indicate that differing environments can alter the efficiency of the various reactions. It is noted, however, that adsorption reactions are not as effective in removing cadmium from solution as they are in removing other heavy metals (Hem, 1972).

Volatilization and photolysis are not important fate-controlling mechanisms for cadmium. However, due to the tendency for cadmium to behave similarly to zinc and its tendency to substitute in carbonate compounds, it is readily bioaccumulated by all organisms (U.S. Environmental Protection Agency, 1979).

Cadmium partitioning coefficients ( $K_d$ s) have not been determined or published for the geologic materials surrounding the S-3 WMA. Concentration ratios calculated from water and sediment analyses from selected wells in the vicinity of the S-3 WMA yield values ranging from 11.3 to 1,200.

### 3.2.3 Mercury

Although mercury may occur in nature as the metallic form, the major commercial source is as cinnabar, mercuric sulfide (HgS). In the conterminous United States, natural mercury concentrations in the soils are reported to range from less than 10 ug/kg to 4,600

ug/kg, the average concentration being 90 ug/kg (U.S. Geological Survey, 1984). The major uses of mercury in the U.S. include the production of electrical apparatus, chlor-alkali apparatus, paint, dental preparations, pesticides, pharmaceuticals, and catalysts.

Mercury can be present in the environment in one of three oxidation states; Hg(0), Hg(I), and Hg(II). The most reduced form is the metal, Hg(0). The mercurous ion, Hg<sup>+</sup>, has an oxidation state of +I, and the mercuric ion, Hg<sup>2+</sup>, has an oxidation state of +II. Within a moderately oxidizing environment of pH above 5, the predominant mercury species will be elemental mercury. Mildly reducing conditions, which are likely to occur in many sediments, can cause the mercury to be precipitated as the sulfide, cinnabar, which has an extremely low aqueous solubility.

Mercury is strongly adsorbed to many types of geologic material. In natural samples, a major portion of the total mercury has been found associated with particulates (Hinkle and Learned, 1969). Inorganic mercury is bound strongly enough by sediments to be transported by sediment mobilization. Mercury adsorption onto sediments is probably the most important process for determining the fate of mercury in the aquatic environment (U.S. Environmental Protection Agency, 1979).

Metallic mercury can enter the atmosphere as a result of volatilization. The rate of vaporization of mercury and certain of its inorganic compounds decreases in the sequence Hg > Hg<sub>2</sub>Cl<sub>2</sub> > HgCl<sub>2</sub> > HgS > Hg<sup>0</sup> (Koksay and Bradshaw, 1969). Organomercury compounds are more volatile than divalent mercury. Methylation of mercury by microbial transformation can result in a net increase in the volatility of mercury.

Bioconcentration factors (BCF) for freshwater fish are reported to range from 11,000 to 81,700 L/kg for methyl mercury (McKim, et al. 1976; Olsen, et al. 1975), and BCFs for freshwater invertebrates are reported at 100,000 L/kg (Chapman, et al. 1968). Methyl mercury is the form of mercury present in most fish tissue. Methyl mercury is

readily accumulated by fish both from their food and through the water. Once mercury has entered the biological system, the depurative half-life of methyl mercury in aquatic organisms can be as long as one to three years (Phillips and Russo, 1978).

#### 3.2.4 Nickel

Nickel is a naturally occurring metal that is found in small quantities in the earth's crust, and in all parts of the environment including plants and animals used for human consumption, air, drinking water, rivers, lakes, oceans, and soils. It is used primarily in making various steels and alloys, and in electroplating. Natural nickel concentrations in soils depend on mineral constituents of the soil. In the conterminous United States natural nickel soil concentrations range from less than 5 to 700 mg/kg, and the average soil concentration is reported to be 19 mg/kg (U.S. Geological Survey, 1984).

Nickel is usually divalent in its compounds, which are predominantly ionic in character. Nickel forms compounds with sulfate, chloride, nitrate, carbonate, oxide, hydroxide, and with organic ligands (Cotton and Wilkenson, 1972). Under reducing conditions and in the presence of sulfur, the insoluble sulfide is formed. Under aerobic conditions and pH below 9, the compounds nickel forms with hydroxide, carbonate, sulfate, and naturally occurring organic ligands are sufficiently soluble to maintain aqueous  $\text{Ni}^{2+}$  concentrations above 60 ug/L (U.S. Environmental Protection Agency, 1979).

Humic acids in natural waters will alter the solubility and precipitation behavior of nickel. In an experiment exposing nickel carbonate to humic acid, Rashid and Leonard (1973) found that 200 mg of nickel was solubilized per gram of humic acid added to the system. Humic acids are ubiquitous in natural waters and may be expected to increase the solubility of nickel under natural conditions to the point that precipitation is probably not a significant fate.

Volatilization and photolysis are not important fate-controlling mechanisms for nickel. In general, nickel is not bioaccumulated in significant amounts by aquatic organisms. In a study of the accumulation of iron, zinc, lead, copper, and nickel by algae collected near a zinc smelting plant, it was found that nickel exhibited the lowest bioconcentration factor of all metals tested (Trollope and Evans, 1976). The average bioconcentration factor (BCF) of nickel is 47 L/kg (Chapman, et al. 1968).

Nickel is a highly mobile metal and is adsorbed only to a small extent. Sorption and precipitation are not as effective for retarding nickel transport as they are with many other metals; however, sorption processes can scavenge nickel from solution (U.S. Environmental Protection Agency, 1979). In natural, unpolluted waters, sorption processes are moderately effective in limiting the mobility of nickel in the aquatic environment, but in more organic-rich, polluted waters, little absorption takes place.

### 3.2.5 Nitrate

Soda niter ( $\text{NaNO}_3$ ) and Niter ( $\text{KNO}_3$ ) are the most common nitrate minerals known. The natural occurrence of these minerals is limited to arid regions and less commonly as crustal precipitates on cave walls. In some areas small quantities of these minerals may be present in loose soils. The high solubility of these minerals limits their occurrence in humid environments (Hurlbut and Klein, 1977).

Nitrogen in the form of nitrate ( $\text{NO}_3^-$ ) is one of the most common contaminants identified in ground water. The sources of nitrate in ground-water systems generally originate outside of the ground-water system, commonly from land sources, such as nitrate wastes and fertilizers, or from organic nitrogen within the soil zone (Hem, 1985). Ground waters become enriched with nitrate due to the leaching action of rainfall as it percolates through the soil zone. In some cases the ground water can become enriched with nitrate directly from rainfall. Rain can be a source of nitrate due to the oxidation of atmospheric

nitrogen during electrical storms and from the burning of fossil fuels. The subsequent contact between the oxidized nitrogen ( $\text{N}_2\text{O}_5$ ) and atmospheric water vapor results in the formation of  $\text{HNO}_3$ , which disassociates in the rainwater.

The normal range of nitrate concentrations in ground water is not controlled by the solubility constraints of nitrate compounds (Freeze and Cherry, 1979). For example, the dissolution of  $\text{Ba}(\text{NO}_3)_2$  (one of the less soluble nitrate compounds with a solubility product of  $K_{sp} = 8.83 \times 10^{-3}$ ) in distilled water results in a barium concentration of approximately  $3.1336 \times 10^{-2}$  moles/liter (4,300 mg/L) and a nitrate  $\text{NO}_3^-$  concentration of  $6.2672 \times 10^{-2}$  moles/liter (3,885 mg/L). Subsequently, the concentration of nitrate in many ground waters tends to increase over time due to man-made inputs such as fertilizer and feedlot wastes.

The nitrate concentration of ground water can be reduced due to uptake by plant roots and the formation of other forms of nitrogen such as ammonia ( $\text{NH}_3$ ), ammonium ( $\text{NH}_4^+$ ), nitrite ( $\text{NO}_2^-$ ), nitrogen ( $\text{N}_2$ ), and nitrous oxide ( $\text{N}_2\text{O}$ ) by denitrification. The formation of these species is theoretically possible in ground waters where the REDOX (oxidation/reduction) potential is less than +250 millivolts (the water should be devoid of oxygen) and the nitrogen within the nitrate anions is reduced to its lower oxidation states (3, 1, 0, and -3). However, the processes responsible for the denitrification of nitrate appear to be biologically controlled, slow, and not well understood (Cherry, et al. 1984).

Nitrate dissolved in water occurs as an anion with a valence of minus one (-1). Nitrate ions will form complexes in solution; however, the bond strengths of the complexes are generally small. The tendency of nitrate to stay in solution (the high solubility of its compounds and its tendency not to degrade), and its anionic form, allows nitrate to travel uninhibited with ground water for long distances.



### 3.2.6 Uranium

Uranium is widely distributed in the natural environment. The average concentration of uranium in crustal rocks is 2.8 mg/kg. The average shale contains approximately 3.7 mg/kg uranium. Most natural occurrences of uranium are associated with magmatic hydrothermal veins and pegmatites. There are over 100 known uranium containing minerals, the most common of which is probably uraninite ( $\text{UO}_2$ ). Economic deposits of uranium are primarily found in conglomerate and sandstone ores (Krauskopf, 1979).

There are three naturally occurring radioactive isotopes of uranium: U-238, U-235, and U-234. Natural occurrences of uranium consist of 99.28 percent U-238, 0.72 percent U-235, and 0.005 percent U-234. U-238 has the longest half-life of the three isotopes (4.5 billion yr), while U-234 has the shortest half-life (247,000 yr). Both U-238 and U-234 decay by emitting alpha particles. The energy of the majority of the nuclear transformations is approximately 5 million electron volts (MeV).

The geochemistry of uranium is predominantly controlled by the pH and REDOX state of the environment (Krauskopf, 1986). In the surface and ground waters uranium is generally present as the divalent uranium dioxide ( $\text{UO}_2^{2+}$ ) complex or in a series of carbonate-uranium complexes which have both positive and negative charges. The form of the complexes is dependent on the concentration of the complexing ligands and the type of ligand (i.e. carbonate, phosphate, organic). In general, under acidic conditions uranium will form positively charged complexes; under neutral to alkaline conditions the complexes are negatively charged. The mobility of uranium is highly dependent on the type of complex (cationic or anionic) formed. The cationic forms should all be adsorbed to some extent on the bedrock substrates. The negatively charged uranium complexes can be very mobile. Under reducing conditions, over the entire range of normal pH, uranium will

precipitate from solution as uraninite, and therefore would be immobile (Olsen, et al. 1986; Drever, 1982; Bondiotti, 1981; Garrels and Christ, 1965).

Site-specific uranium  $K_d$ s have been determined by Bondiotti (1981). Bondiotti conducted laboratory studies on the Conasauga Formation during which he calculated retardation factors and partitioning coefficients for numerous radionuclides and transuranics. The uranium  $K_d$  values obtained by Bondiotti ranged from 14 to 41 milliliters per gram (mL/g). Olsen, et al. (1986) indicated that uranium concentration ratios (sediment/solution), calculated from samples obtained from the field, ranged from 62 to 1,400 mL/g. They also indicated that the ratio was highly dependent on the pH of the solution and the total phosphorus content of the ground water. The relative importance of carbonate complexes, which may be present in the S-3 Site ground waters, were not determined. Estimates from field analyses in the vicinity of the S-3 Site appear to be in general agreement with laboratory values. Concentration ratios for selected wells in Bear Creek Valley range from 2.2 to 100.

### 3.2.7 Tetrachloroethene

Tetrachloroethene (PCE) is a synthetic chemical compound with no known natural sources. It is produced in great quantities for use in the dry cleaning, metals degreasing and textile processing industries. The dry-cleaning industry accounts for the majority of PCE applications, where it is used as the primary cleaning agent. Most PCE is released to the environment by evaporation during use. The remainder generally is disposed as liquid or solid wastes heavily contaminated with grease and oil.

Tetrachloroethene has a solubility in water of 150 to 200 mg/L and a vapor pressure of 17.8 mm Hg at 20°C (U.S. Environmental Protection Agency, 1986b). Henry's Law constant has been reported at  $2.59 \times 10^{-2}$  atm-m<sup>3</sup>/mole (U.S. Environmental Protection

Agency, 1986b). These numbers suggest that evaporation is a very important removal mechanism for PCE from surface waters.

Roy and Griffin (1985) have classified PCE as having medium mobility based on adsorption phenomena. The logarithm of the octanol/water partition coefficient is reported at 2.6 (U.S. Environmental Protection Agency, 1986b). Other sources suggest only slight sorption (U.S. Environmental Protection Agency, 1979).

Biodegradation of PCE in the ground-water environment appears to be very slow. Thom and Agg (1975) consider PCE "potentially biodegradable" by biological sewage treatment provided suitable acclimatization can be achieved. Tobak (1981) found PCE to exhibit significant degradation with gradual adaptation. Parsons, et al. (1984) and Vogel, et al. (1985) report degradation of PCE in ground water to trichloroethene and then to dichloroethene and vinyl chloride.

Volatilization of PCE from surface waters to the atmosphere where rapid decomposition takes place is a major transport process. There are two major environmental fates for PCE in ground water. One is transportation in the ground water to a point of surface discharge where volatilization and decomposition can occur. The competing fate is biodegradation of PCE in the ground water. Which fate will predominate depends on the distance to the point of discharge and the site-specific degree of sorption as well as the activity of microflora.

### 3.2.8 Trichloroethene

Trichloroethene (TCE) has numerous solvent applications in both the industrial and consumer markets and a variety of other uses, including use as a chemical intermediate and heat-transfer media. Approximately 200 million lbs of TCE is used in the U.S. annually, the majority (80%) being used as a solvent for the vapor degreasing of metal fabricated

parts (Chemical Marketing Reporter, 1986). Prior to 1977, TCE was used as a general and obstetrical anesthetic, grain fumigant, skin, wound and surgical disinfectant, pet food additive, and extractant of spice oleo resins in food and of caffeine for the production of decaffeinated coffee (International Agency for Research on Cancer 1979).

Most of the TCE used in the U.S. is released to the environment by evaporative losses. By far, the major TCE emission source to the environment is vapor degreasing operations, which eventually release most of the TCE used in this application to the atmosphere (Pandullo, et al. 1985). Other relatively minor emission sources include release from TCE and other chemical manufacturing, solvent evaporation from adhesives, paints, coatings, and miscellaneous uses, volatilization from wastewater treatment facilities, and gaseous emissions and leaching to ground water at waste disposal sites.

TCE has a water solubility of 1,100 mg/L, a vapor pressure of 57.9 mm Hg at 20°C, and a Henry's Law constant of  $9.1 \times 10^{-3}$  atm-m<sup>3</sup>/mole (U.S. Environmental Protection Agency, 1986b). TCE volatilizes rapidly from water, although actual volatilization rates are dependent upon a number of factors, including temperature, water movement and depth, and associated air movement (Dilling, 1977; U.S. Public Health Service, 1988). Estimated volatilization half-lives from typical environmental bodies are: pond, 11 days; lake, 4 to 12 days; and river, 1 to 12 days (U.S. Environmental Protection Agency, 1987b). The major route of removal of TCE from water is volatilization (U.S. Environmental Protection Agency, 1987b).

TCE is highly mobile in soil (Wilson, et al. 1981). Soil sorption coefficients range from 41 to 42, and significant movement of TCE in soil was demonstrated in soil/bank infiltration systems in which TCE was observed to leach rapidly to ground water (Giger et al. 1983; Bouwer et al. 1984). This high soil mobility also indicates that TCE will not partition significantly from the water column to sediment in bodies of water.

An experimentally measured bioconcentration factor (BCF) of 17 L/kg in fish was reported for TCE (Veith et al. 1980; Barrows et al. 1989). TCE has a low bioaccumulation potential in fish. This is supported by monitoring of TCE concentrations in seawater and associated aquatic organisms (Pearson and McConnell, 1975; Dickson and Riley, 1976).

Most TCE released to the environment is transferred to the atmosphere, and the dominant transformation process in the atmosphere is reaction with sunlight-produced hydroxyl radicals. Estimated half-life in the atmosphere is 6.8 days (Atkinson, 1985). In natural water and soil systems, biodegradation may be the most important transformation process, although it does not appear to occur rapidly. The primary biodegradation product from TCE is dichloroethene, although small amounts of vinyl chloride may also be formed (Smith and Dragun, 1984). Because biodegradation does not occur at a rapid rate, most TCE present in surface waters can be expected to volatilize to the atmosphere. Volatilization will not be a viable process for most of the TCE transported into ground water by leaching. There is evidence that slow biodegradation of TCE occurs under anaerobic conditions (Barrio-Lage et al. 1987; Wilson, et al. 1986), suggesting that a slow biodegradation process may occur in the ground water.

### 3.3 SUMMARY

Eight constituents were identified as representing the greatest potential for exposure and hazard. Barium, cadmium, mercury, nickel, nitrate, uranium, PCE and TCE are representative of the principal risk associated with waste constituents released from the S-3 WMA. Nitrate is the most mobile constituent and is present in the ground water in the highest concentrations. Mercury, cadmium, and to a lesser extent uranium, have the greatest potential for concentrating in either sediments or the biota. PCE and TCE had much lower indicator chemical evaluation scores; however, they are more volatile than the other indicator chemicals and they are both suspect carcinogens indicating a higher level of

potential public concern. Of the eight indicator chemicals only PCE and TCE were not detected in surface water or sediment samples. This is expected because of the rapid attenuation of volatile organics in surface waters.

## 4.0 EXPOSURE ASSESSMENT

In order for a risk to exist, both exposure and hazard must be present. This section addresses the potential for exposure to constituents from the S-3 WMA. In order for exposure to occur there must be a source of chemical release, a mechanism of transport to, and a population at a point of exposure. Exposure will not occur if these factors are not present. Potential exposure pathways identified at the S-3 WMA are listed in Table 4-1.

### 4.1 RELEASE SOURCE ANALYSIS

The S-3 Ponds are presently closed and capped. Surficial contamination of the soils presently exist at the Salvage Yard, the Interim Drum Storage Yard, and the Rust Garage; however, until closure activities at these sites are complete, and guidelines for releases are covered under the facility operation procedures, those releases contained within the confines of these units will not be considered a release to the environment. Only constituents migrating beyond the boundaries of the S-3 WMA will be identified as released to the environment.

Ground water and surface waters are the principal media exhibiting evidence of past releases from the S-3 WMA. Infiltration of rainwater through the permeable surface soils has carried constituents into the ground water. Past and potential future discharge of the impacted ground water to Bear Creek and East Fork Poplar Creek are potential pathways for constituents in the surface waters.

There is no drinking-water usage of the ground water within the DOE property boundaries around the S-3 WMA, nor are there any projected or potential uses. Ground water is extracted from a well upgradient of the contamination in Bear Creek Valley for use in unsaturated zone monitoring devices. The geologic formation containing the bulk of the reported constituents, the Nolichucky Shale, exhibits poor yields and has a low potential

Table 4-1. Potential Pathways of Exposure to Constituents Associated with the S-3 Waste-Management Area

Medium	Factors Influencing Exposure		Environmental Considerations	Potentially Exposed Population	Pathway Exists	Potential of Exposure
	Exposure Route	Physical /Chemical Properties				
Ground Water	Ingestion	Absorption of metals to aquifer media retard migration	On existing or planned potable wells within 0.5 miles of site	None	No	None
	Dermal Contact	Absorption of metals through skin is low	Monitor wells located within plume	Researchers and contractors investigating plume ("Investigators")	Yes	Possible
Air	Inhalation	Organic constituents and mercury are volatile, potentially released at discharge areas	Frequency of monitor well access and pumping rates are low	Investigators	Yes	Possible
Surface Water	Ingestion	Precipitation, adsorption and volatilization active attenuation processes	No human potable uses of surface water	Wildlife and fish	Yes	Possible
	Dermal Contact	Absorption of metals through skin is low	Recreational uses restricted to areas downstream	Investigators	Yes	Possible
Soils	Dermal Contact/ Ingestion	Organic constituents rapidly released to atmosphere. Metals adsorbed to soils.	Headwaters of Bear Creek dry over part of year	Investigators	Yes	Possible
Food	Ingestion of contaminated game or fish	Precipitation, adsorption to soils and volatilization active processes removing constituents from solution	Hunter or fisherman access limited to area downstream of ground-water discharge areas	Hunters / Fisherman	Yes	Possible



for exploitation as a source of ground water. Thus, release of constituents in the ground water is associated with the discharge to the surface waters.

Constituents released to the surface waters could be precipitated out of solution, adsorbed to the sediments, volatilized to the atmosphere, or taken up by the biota. Samples collected weekly during 1987 from upper Bear Creek near the S-3 Site (BCK 12.4) contained neither of the organic indicator constituents, but did contain elevated average concentrations of nitrate and uranium (see Table 3-2). Volatilization of the organic constituents appears to be effective in removing these constituents from the surface waters as rapidly as they are discharged from the ground water. Weekly water quality samples for 1987 from New Hope Pond influent, which are an indicator of East Fork Poplar water quality, contained lower concentrations of nitrate and uranium, but higher concentrations of mercury. These elevated mercury concentrations are not associated with discharge of mercury presently identified in the ground water at the S-3 WMA. Thus, based on the 1987 monitoring data, the effects of ground water discharges are more clearly identified with Bear Creek than with East Fork Poplar Creek.

Bear Creek flows southwestward from its headwaters just south of the S-3 Site (BCK 12.4) for approximately 4.5 miles where it turns northward through Pine Ridge to flow into East Fork Poplar Creek, which discharges into Poplar Creek 6 miles upstream of the Clinch River. The headwaters of East Fork Poplar Creek are formed by the buried storm sewer system and open drainage channel located near the west end of the Y-12 Plant. Streamflow in East Fork Poplar Creek at the headwaters is almost entirely composed of discharged process and cooling waters from the Y-12 Plant. These waters formerly flowed into New Hope Pond, but now have been diverted to Lake Reality. East Fork Poplar Creek flows through a gap in Pine Ridge into the developed areas of Oak Ridge, and then southwest to its confluence with Poplar Creek. Inorganic constituents detected in East Fork Poplar Creek sediments and water are the result of past Y-12 Plant process

discharges (TVA 1986) and not migration of contaminated ground water from the S-3 WMA. Thus, there is not evidence of off-site releases of constituents from the S-3 WMA.

The S-3 WMA is located well within DOE property boundaries. Identified constituent plumes do not extend beyond DOE property. Investigation of the S-3 WMA site has identified constituents in the ground water, and the waters and sediments of Bear Creek. Bear Creek and East Fork Poplar Creek have been identified as potential discharge points for constituents presently in the ground water. Neutralization, biodegradation, and capping of the S-3 Ponds have significantly reduced or eliminated that original source of contamination. The major mass of constituents now resides in the ground-water and aquifer media surrounding the site, and attenuation processes are decreasing concentrations in these media as a function of time.

#### 4.2 EXPOSURE PATHWAYS

Bear Creek and East Fork Poplar Creek are the primary discharge areas for the S-3 WMA contaminant plumes. There is no current use of the ground water at the DOE facility within the S-3 WMA. Thus, the headwaters of Bear Creek and East Fork Poplar Creek are the primary exposure points for human or environmental exposure. Headwaters for East Fork Poplar Creek are located in a buried storm sewer system, which flows into a open drainage channel. The initial exposure point for East Fork Poplar Creek would be the open drainage system. Mean flow in East Fork Poplar Creek is approximately 12.4 cfs, which is approximately equal to the volume of process and cooling water discharge from the Y-12 plant. Base flow contribution to East Fork Poplar Creek is low in comparison to total streamflow. Thus, the potential for exposure and extent of exposure is greater for Bear Creek than for East Fork Poplar Creek.

Bear Creek flows through controlled land (DOE reservation) and is not used for recreational purposes. Mean flow in Bear Creek for the period April 1984 to December

1986 was 1.06 cubic feet per second (cfs), with 60 percent contribution from base flow (Geraghty & Miller, Inc., 1988a). Public access to the Y-12 Plant is controlled by security personnel. Bear Creek leaves the Y-12 Plant at U.S. Route 95 (BCK 4.55), which is approximately 5 mi downstream of the S-3 Site. Public access to Bear Creek is possible at this location. Additionally, hunters are permitted access to Bear Creek Valley within approximately 3.7 mi of the S-3 Site (BCK 6.23). Closest exposure point for hunters is 3.7 mi downstream, and closest exposure for fishermen or swimmers is 5 mi downstream.

Annual hunts are conducted on the DOE reservation to control the deer population. Hunters are not permitted access to the Y-12 Plant. The closest point at which a hunter may access Bear Creek is at Gum Hollow (BCK 6.23). Hunts are restricted to four weekends, two for archers and two for shotgun and muzzle-loader hunters. There are permits for 1000 archers per weekend and 900 gun-hunters per weekend. The deer harvest for the Oak Ridge Reservation in 1987 was 441 deer (Martin Marietta Energy Systems, 1988). All deer are monitored for radioactivity with portable NaI detectors before they are released to the hunters for consumption.

The closest point of exposure to East Fork Poplar Creek for the general public is at Scarboro Road, which is downstream of Lake Reality. Fishing is not permitted in New Hope Pond, Lake Reality, the upper reaches of Bear Creek (above BCK 4.55), or in East Fork Poplar Creek above Bear Creek Road where it leaves the DOE facility. Fish, invertebrates, and amphibians were collected from East Fork Poplar Creek and Bear Creek in 1984 and 1985 (TVA, 1986). Of the S-3 WMA indicator constituents, the biota samples contained only elevated levels of mercury and cadmium. The high levels of mercury in East Fork Poplar Creek are associated with past plant operations, and not seepage of ground water impacted by the S-3 WMA. PCBs have also been reported in the sediments at the headwaters of Bear Creek; however, PCB concentrations in the biota were not found.

to be elevated above background or health criteria. PCBs in Bear Creek are not identified as a potential food chain hazard.

Researchers and waste-management personnel working in Bear Creek Valley have the greatest potential for exposure. Reported constituent concentrations associated with the S-3 WMA have been highest at the Bear Creek headwaters. Researchers have the highest potential of exposure along this stretch of Bear Creek and are identified as the primary population potentially exposed via dermal contact with Bear Creek waters or sediments.

Bear Creek is identified as a perennial stream downstream of the confluence of Spring SS-5 and Bear Creek (BCK 9.41). Thus, during dry periods, aquatic populations that have not migrated downstream may be exposed to concentrations very close to ground water concentrations, as the base flow will comprise almost the entire flow in this portion of Bear Creek.

East Fork Poplar Creek is inaccessible at the headwaters, which are located in the buried storm sewer. Access to the open drainage channel, New Hope Pond or Lake Reality is limited to Y-12 Plant employees. Personnel involved with wastewater discharge or investigation of water quality are the most probable exposed population for East Fork Poplar Creek. Exposure levels assessed for this small subpopulation of the Y-12 Plant would be greater than levels associated with potential infrequent exposures of other plant employees.

Direct exposure to constituents in the ground water is dependent on a supply well intercepting the constituent plume. Most industrial and drinking-water supplies in the Oak Ridge area are provided by surface-water sources. There are 13 public ground-water supply systems within approximately 20 miles of the S-3 WMA (Geraghty & Miller, Inc., 1988a). The closest public supply is the spring supplying Oliver Springs, which is about 7.5 miles north-northeast of the S-3 WMA, and serves approximately 4,000 people. The

nearest industrial ground water user is located approximately 5.2 miles northeast of the site. Two private wells used to supply drinking-water are located within 3.1 miles of the S-3 WMA. They are approximately 0.7 miles and 1.4 miles from the S-3 Site, but are located north of Pine Ridge, which forms a ground-water flow boundary for Bear Creek Valley. Several other wells were inventoried outside of a 3 mi radius of the S-3 WMA, but all identified wells are outside the Bear Creek watershed and could not intercept the contaminant plumes.

Current ground-water uses on the DOE reservation are 2 wells and 1 spring supplying tanks at the Oak Ridge National Laboratory (ORNL) Aquatic Laboratory, and one monitoring well located in the Bear Creek Valley Burial Grounds used for a lysimeter demonstration study. The ORNL Aquatic Laboratory water supply is located approximately 4 mi from the S-3 WMA, and is not affected by the S-3 WMA constituent plume. The lysimeter demonstration study should not involve significant exposure potential due to the position of the well upgradient of the constituent plume and the low volume of water needed for the study.

Collection of ground-water samples from the network of monitor wells used to investigate the constituent plumes are potential exposure pathways for the personnel collecting the samples. Dermal contact and low level inhalation exposure are possible; however, frequency of exposure is low (average 52 sampling days per year, 2 hours of exposure per sampling day, and safety precautions have been instituted).

Inhalation of volatile organics or mercury released during collection of monitor-well samples, or released from the surface-water bodies following ground-water discharge are potential pathways of exposure. Exposure levels from the surface-water releases are governed by many parameters, including the rate of ground-water seepage, dispersion in the surface waters and air, ambient temperature, wind speed, and proximity to the

discharge area. Factors affecting exposure levels from the monitor wells include well ventilation, pumping rates, ambient temperature, wind speed and sampling equipment. In general, the level of exposure from either surface-water volatilization or monitor-well sampling are expected to be low due to the high levels of aquatic and atmospheric dispersion.

Surficial soils immediately surrounding the S-3 Site are not a source of waste constituents following closure of the ponds. Operations at the others sites within the S-3 WMA are subject to control measures to limit uncontrolled releases. Clean-up procedures and worker guidelines that are in place are designed to protect the workers at the sites. Offsite exposure to potential constituents in the surficial soils are unlikely due to control of runoff and dust suppression.

The headwaters of Bear Creek are dry during portions of the year, and direct exposure to the sediments in the creek bed has a higher probability. Exposure to these sediments and the alluvial deposits on the banks of Bear Creek and East Fork Poplar Creek are potential routes of exposure for personnel accessing the creeks. The population having the greatest potential for exposure to impacted sediments are the researchers studying the water quality or biota of the creeks.

The most sensitive population for assessment of exposure would be a research employee or contractor studying the water quality or biota of Bear Creek and East Fork Poplar Creek, monitoring the ground water, and catching fish downstream for personal ingestion. This is a hypothetical worst-case exposed population. Most exposed populations at the Oak Ridge Facility would be exposed by only one or two of the identified exposure pathways.

### 4.3 EXPOSURE ANALYSIS

Potential exposure dosages were calculated for the dermal contact and ingestion routes of exposure to the surface water, sediments, ground water, and fish. Dosage levels are identified as milligram of the constituent per kilogram of body weight per day (mg/kg/day). The equations and many parameters used to calculate dosage are adapted from the Superfund Exposure Assessment Manual (U.S. Environmental Protection Agency, 1987a), and are listed in Appendix A. Exposure dose levels for all pathways that will be discussed are listed in Table 4-2.

Exposure scenarios and parameters used in the initial calculations of exposure dose levels are conservative worst-case estimates. Actual exposure dose levels would be lower. The conservative assumptions are used as an initial screening tool. If the conservative exposure levels result in no hazards, then exposure would also be acceptable using more realistic assumptions. Were the exposure dose levels using the worst-case assumptions to demonstrate a potential hazard, the exposure scenarios would be re-evaluated using more realistic assumptions. Hazards levels and reassessment of exposure parameters are discussed in the risk characterization section.

#### 4.3.1 Surface Water

Dermal contact and ingestion of small quantities of water by researchers accessing the upper reaches of Bear Creek and East Fork Poplar Creek was assessed assuming a 5-year research project that required access to the creek 260 days a year (5-day week for 52 weeks) for a total of 1300 days of exposure over a 70-year ( $2.56 \times 10^4$  day) lifetime. Little research of the creeks is normally conducted in the winter months, therefore, this exposure frequency is considered a high estimate of exposure for a field research project.

Table 4-2. Exposure Dose Levels for Contaminants Associated with the S-3 Waste-Management Area

Constituent	Exposure Pathways					
	Surface Water <sup>a</sup> BC <sup>e</sup>	EFPC <sup>f</sup>	Sediment <sup>b</sup> BC	EFPC	Ground <sup>c</sup> Water	Fish <sup>d</sup> BC EFPC
Barium	6.3 x 10 <sup>-7</sup>	4.4 x 10 <sup>-7</sup>	— <sup>h</sup>	—	3.8 x 10 <sup>-5</sup>	—
Cadmium	2.5 x 10 <sup>-8</sup> g	1.2 x 10 <sup>-8</sup> g	5.0 x 10 <sup>-7</sup>	1.9 x 10 <sup>-7</sup>	7.9 x 10 <sup>-8</sup>	2.2 x 10 <sup>-6</sup> 1.2 x 10 <sup>-6</sup>
Mercury	1.7 x 10 <sup>-9</sup> g	6.8 x 10 <sup>-8</sup>	6.8 x 10 <sup>-8</sup>	8.3 x 10 <sup>-6</sup>	6.9 x 10 <sup>-9</sup>	4.8 x 10 <sup>-5</sup> 1.2 x 10 <sup>-4</sup>
Nickel	3.3 x 10 <sup>-8</sup> g	3.8 x 10 <sup>-8</sup> g	9.6 x 10 <sup>-6</sup>	4.2 x 10 <sup>-6</sup>	1.7 x 10 <sup>-6</sup>	—
Nitrate (as N)	3.0 x 10 <sup>-3</sup>	4.7 x 10 <sup>-5</sup>	—	—	3.5 x 10 <sup>-3</sup>	—
Uranium	8.1 x 10 <sup>-6</sup>	5.8 x 10 <sup>-8</sup>	4.5 x 10 <sup>-6</sup>	—	2.0 x 10 <sup>-6</sup>	—
Tetrachloroethene	7.5 x 10 <sup>-8</sup> g	7.5 x 10 <sup>-8</sup> g	—	—	4.4 x 10 <sup>-7</sup>	—
Trichloroethene	7.5 x 10 <sup>-8</sup> g	7.5 x 10 <sup>-8</sup> g	—	—	5.3 x 10 <sup>-8</sup>	—

NOTE: Dosages reported in milligrams per kilogram body weight per day (mg/kg/day)

<sup>a</sup> Dermal contact and ingestion of creek water during stream investigation

<sup>b</sup> Dermal contact and ingestion of sediments during stream investigation

<sup>c</sup> Dermal contact and ingestion of ground water during monitoring

<sup>d</sup> Ingestion of fish from creeks

<sup>e</sup> BC = Bear Creek

<sup>f</sup> EFPC = East Fork Poplar Creek

<sup>g</sup> Average constituent concentration below detection limit; dosage based on one half the detection limit

<sup>h</sup> Constituents below analytical detection limits or not analyzed for (TVA 1986)

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Exposure parameters used in the calculation include: 1) dermal exposure of arms and legs (skin surface area of 10,260 cm<sup>2</sup> [U.S. Environmental Protection Agency, 1984]); 2) flux of constituent across skin equal to water flux rate across the skin (0.5 mg/cm<sup>2</sup>-hr [U.S. Environmental Protection Agency, 1984]); 3) absorption factor of 12% for inorganic metals and 100% for organics and nitrate (Hawley, 1985); 4) ingestion rate of 10 mL/day; and 5) adult body weight of 70 kg (U.S. Environmental Protection Agency, 1988). Average surface water concentrations from samples collected weekly from Bear Creek near the S-3 Site, and East Fork Poplar Creek at the influent to New Hope Pond were used as a constant exposure concentration for the 1300 days of exposure.

The equation used to calculate surface-water dose levels is listed in Appendix A (Table A.1). Dose levels for Bear Creek and East Fork Poplar Creek are listed in Table-4-2.

#### 4.3.2 Sediment

Dermal contact and ingestion of small quantities of the sediments of Bear Creek and East Fork Poplar Creek were estimated for a researcher accessing the river for the same 1300 days (260 days per year for 5 years) that was used to estimate surface water exposure.

Parameters used to calculate exposure dose levels for the sediments include: 1) sediment contact with the hands and feet (1,740 cm<sup>2</sup> [U.S. Environmental Protection Agency, 1984]); 2) dust, comparable to commercial potting soil, adherence to the skin (1.45 mg/cm<sup>2</sup>-day [U.S. Environmental Protection Agency, 1988]); 3) absorption factor of 12% for the inorganics and 100% for the organics and nitrate (Hawley, 1985); 4) media matrix effect on absorption of 15% (Hawley, 1985); 5) soil ingestion rate of 100 mg/day (U.S. Environmental Protection Agency, 1988); and 6) adult body weight of 70 kg (U.S.

Environmental Protection Agency, 1988). Average sediment concentrations from Bear Creek and East Fork Poplar Creek were used (Tennessee Valley Authority, 1986).

The equation used to calculate sediment dose levels is listed in Appendix A (Table A 2). Dose levels for Bear Creek and East Fork Poplar Creek are listed in Table 4-2.

#### 4.3.3 Ground Water

Exposure to ground water pumped from monitor wells was estimated for an investigator exposed while collecting samples 52 days per year with 2 hours of exposure per day, for a 10-year period (total of 120 days of exposure). This exposure estimate is consistent with the ongoing ground-water sampling program conducted at the S-3 WMA. The other potential exposure point for direct contact to the ground water near the S-3 WMA would be at the lysimeter study site. Exposure frequency and duration is not expected to exceed the 120 day exposure period and the potential for exposure to the highest concentrations in the ground water is lower. Therefore, the monitor-well sampler is identified as the most sensitive population.

Assumptions used in estimating the dose levels for ground-water exposure include:

- 1) exposure of hands and arms ( $3,420 \text{ cm}^2$  [U.S. Environmental Protection Agency, 1984]);
- 2) constituent flux across skin equal to water flux across skin ( $0.5 \text{ mg/cm}^2\text{-hr}$  [U.S. Environmental Protection Agency, 1984]);
- 3) absorption factor of 12% for inorganics and 100% for organics and nitrates (Hawley, 1985);
- 4) ingestion rate of 10 mL/day; and
- 5) adult body weight of 70 kg (U.S. Environmental Protection Agency, 1988).

Average concentrations detected in the monitor wells is used as a constant exposure concentration over the 10 year exposure period.

The equation used to calculate ground-water dose levels is listed in Appendix A (Table A.3). Dose levels for Bear Creek and East Fork Poplar Creek are listed in Table-4-2.

#### 4.3.4 Fish

Ingestion of fish caught in Bear Creek or East Fork Poplar Creek is an exposure pathway where a population other than Y-12 Plant employees or contractors may be an equally sensitive population. Exposure dose levels were estimated for ingestion of fish from the creeks over a 70-year lifetime.

Parameters used in calculating the fish-ingestion dose level include: 1) average fish ingestion rate of 6 grams per day (U.S. Environmental Protection Agency, 1988); and adult body weight of 70 kg (U.S. Environmental Protection Agency, 1988). Fish tissue concentrations from fish collected in East Fork Poplar Creek and Bear Creek in 1984 and 1985 (TVA, 1986) are used as a constant fish concentration over the 70-year lifetime exposure period.

The equation used to calculate fish-dose levels is listed in Appendix A (Table A.4). Dose levels for Bear Creek and East Fork Poplar Creek are listed in Table 4-2.

## 4.4 SUMMARY

Existing potential exposure pathways for constituents released from the S-3 WMA are dermal contact and incidental ingestion of water or sediments from Bear Creek or East Fork Poplar Creek, dermal contact and incidental ingestion of ground water pumped from monitor wells during sampling, and ingestion of fish caught beyond the DOE reservation boundaries. The point-of-exposure for each of these pathways closest to the S-3 WMA are shown in Figure 4-1. The most sensitive population identified are researchers or contractors of the Oak Ridge facility that are conducting investigations of the water quality

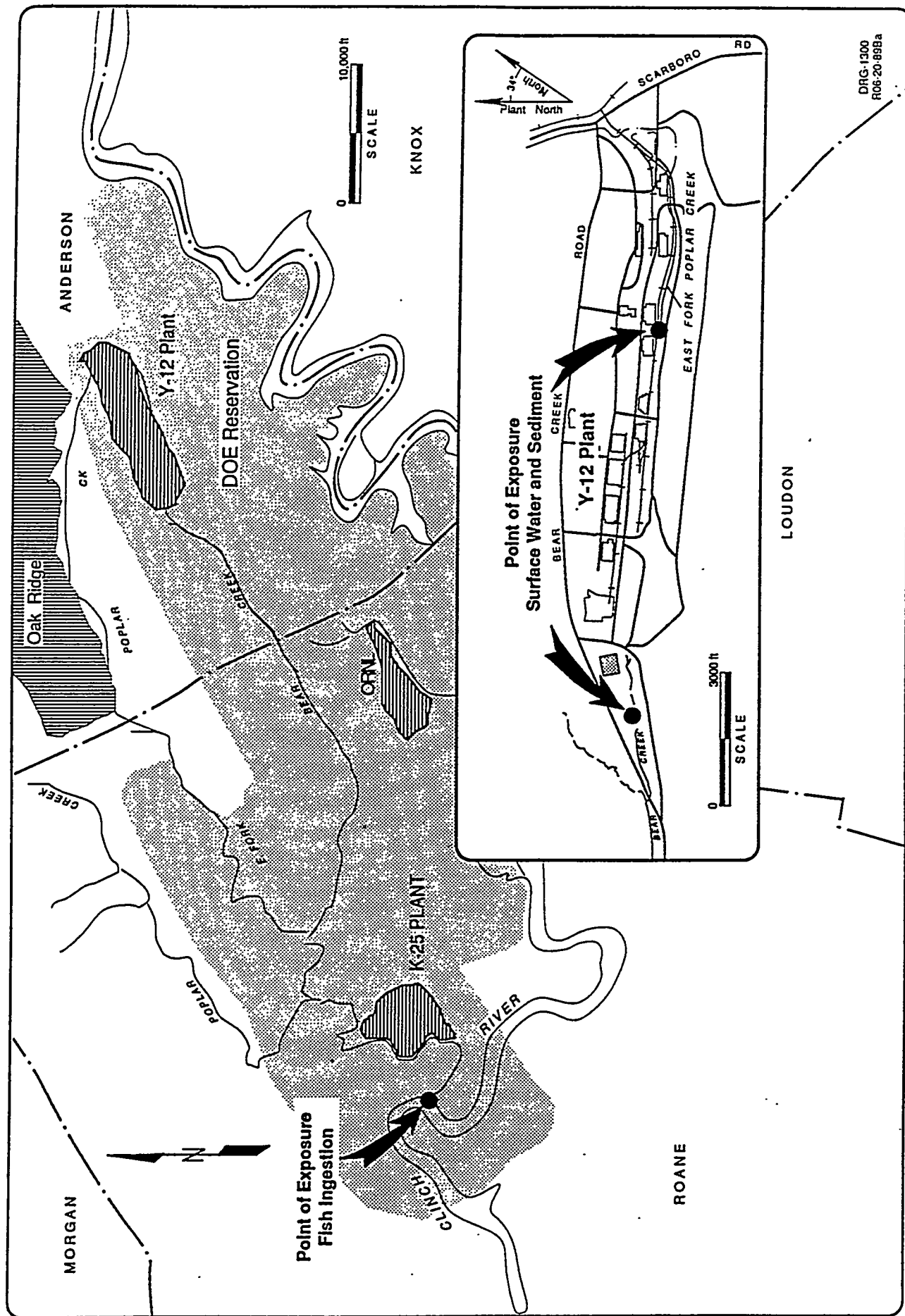


Figure 4-1. Points of Exposure for the S-3 Waste-Management Area

of the creeks and ground water. A specific population of recreational fishermen frequenting either Bear Creek or East Fork Poplar Creek was not identified. Potential periods of exposure were assumed to be in the range of 5 to 10 years for investigations of water quality investigations, but a lifetime of potential exposure was assumed for the fish ingestion exposure pathway. Parameters and equations used to calculate the exposure dose levels are primarily based on standard U.S. Environmental Protection Agency exposure assessment methodology (U.S. Environmental Protection Agency, 1988). Equations used are listed in Appendix A.

## 5.0 HAZARD ASSESSMENT

The inherent risk associated with exposure to the constituents at the S-3 WMA is a function of the amount of exposure, quantity present, and the toxicity of the constituent. Dermal contact and ingestion are identified as the dominant potential routes of exposure (Section 4.0). Of the eight indicator chemicals, the two organic constituents (PCE and TCE) and nitrate have the greatest potential for dermal absorption. Heavy metals have a relatively low potential for skin absorption (Commission of the European Communities 1978). Local adverse dermal responses at a site of exposure were not noted in the literature. Thus, systemic adverse responses, threshold limit doses, and non-threshold responses were identified for the indicator chemicals.

### 5.1 TOXICITY

The recognized toxic responses associated with the indicator chemicals are summarized in Table 5-1. A major distinction in the classification of toxic effects is between carcinogenic and noncarcinogenic effects. Due to the current regulatory approach to carcinogens, acceptable levels of exposure are based on extremely low hypothetical cancer incidence rates rather than the observed finite threshold limits used for noncarcinogens. The level of risk associated with carcinogenic effects is usually much higher than noncarcinogenic effects because of the threshold approach in assessing exposure to carcinogenic constituents.

#### 5.1.1 Noncarcinogenic Effects

Noncarcinogenic responses are believed to have a finite threshold dose, below which adverse responses are not elicited. A single compound might elicit several adverse effects depending on the dose and the length and route of exposure. In developing criteria or standards for a compound, the critical toxicity value or dose which elicits the most

Table 5-1. Summary Toxicity Profiles of Indicator Chemicals Detected at the S-3 Waste-Management Area

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
Barium	Gastroenteritis, muscular paralysis, and ventricular fibrillation from oral ingestion of soluble barium. Strong prolonged stimulant action on muscle.	Insoluble forms of barium are not toxic due to limited absorption. Baritosis, a benign pneumoconiosis, is an occupational disease arising from inhalation of barium sulfate dust.	USEPA Group D - Not classified. No evidence of carcinogenicity in human or animal experiments.	No evidence of mutagenicity or teratogenicity.
Cadmium	For acute exposures symptoms of cadmium toxicity include nausea, vomiting, diarrhea, muscular cramps, and salivation. In severe intoxication, symptoms include sensory disturbances, liver injury and convulsions. In fatal intoxications, those symptoms are followed by shock and/or renal failure and cardio-pulmonary depression. Estimated acute human lethal dose is 350 to 35,000 mg for a 70-kg adult.	Chronic oral exposures can result in pain, osteomalacia, osteoporosis, proteinuria, glucosuria, and anemia. Kidneys are the most sensitive tissue to low level chronic exposure.	USEPA Group D - Not classified for oral exposure and Group B1 - Probable human carcinogen via inhalation exposure. Lung and prostate cancer result from inhalation of cadmium. No evidence of carcinogenicity from chronic oral exposure.	Cadmium does not readily cross the skin. The diet is the major source of human exposure to cadmium (34 µg/day). A non-essential element.
Mercury	Inorganic mercury is not highly toxic as an acute poison. Ingestion of high concentrations can result in gastrointestinal distress and severe anuria and uremia.	Behavioral & neurological disturbances associated with effects on the CNS. Target organs for organomercury compounds are the CNS, peripheral nervous system and kidney.	USEPA Group D - Not classified. No evidence of carcinogenicity except site sarcomas in rats dosed by intraperitoneal injection.	Organomercury compounds are teratogenic and embryotoxic.
Nickel	Dermatitis, acute chemical pneumonitis are reported in workers. Low oral acute toxicity.	Dermatitis and other dermatological effects. Nasal mucosal injury, rhinitis and nasal sinusitis have been reported in workers. Relatively low oral toxicity.	USEPA Group A - Human carcinogen via inhalation exposure. Insoluble dust of nickel subsulfide and nickel oxide have been identified as human carcinogens via inhalation exposure. No evidence of carcinogenicity via oral exposure.	Several nickel compounds are mutagenic. No evidence of teratogenicity or reproductive toxicity.
Nitrate	Acute poisoning very rare because one-time ingestion of about 0.5 gm required.	Methemoglobinemia, particularly in infant less than 3 to 4 months old, due to conversion of nitrates to nitrites in GI tract.	USEPA Group D - Not classified. No evidence of carcinogenicity in humans or animal laboratory experiments.	No evidence of mutagenicity.

Table 5-1. Continued...

Constituent	Acute Toxicity Summary	Chronic Toxicity Summary	Cancer Potential	Other
Uranium	Acute renal damage associated with soluble uranium compounds. Reversible, if damage is not too severe.	Renal toxicity, including albuminuria, elevated blood urea nitrogen and loss of weight.	USEPA Group A - Ionizing radiation, human carcinogen. Ionizing radiation has the potential for being carcinogenic. No evidence of chemical carcinogenicity.	Mutagenic effect of ionizing radiation.
Trichloroethene	Manifestation of TCE exposure is depression of the CNS which is demonstrated by dizziness, headache, visual disturbances, incoordination similar to that induced by alcohol, tremors, sleepiness, nausea, and vomiting. Cardiac arrhythmias and death due to ventricular fibrillation and cardiac arrest as a result of acute exposure above 15,000 ppm. Accidental ingestion of about 150 ml resulted in acute kidney failure, with liver & cardiovascular damage. Local exposure to TCE vapors may cause irritation to eyes, nose, and throat.	Prolonged occupational exposures to vapors (200 to 400 ppm) resulted in CNS symptoms including headache, dizziness, nausea, tremors, sleepiness, fatigue and vomiting. These symptoms were reversible. Lower human exposures (100 to 200 ppm) resulted in biochemical changes in liver function. In test animals, chronic exposure to TCE includes low to moderate liver and kidney toxicity. Prolonged inhalation exposures to test animals at levels greater than 2,000 mg/m resulted in renal toxicity, hepatotoxicity, and neurotoxicity.	USEPA Group B2 - Probable human carcinogen. Has produced increases in hepatocellular carcinomas in mice after oral administration. Other tests with mice and rats have produced negative results.	Mutagenic in salmonella typhimorium and E-coli K-12 strain.
Tetrachloroethane	Short-term inhalation exposure in humans can result in depression of the CNS characterized by dizziness, impaired memory, confusion, irritability, "inebriation-like" symptoms, tremors and numbness. Kidney impairment, hepatitis, and enlargement of the spleen and liver have been reported.	Very little data is available concerning long-term exposure to PCE. Hepatotoxic effect have been documented for long-term inhalation exposures to workers as have hepatitis, cirrhosis, liver-cell necrosis, enlarged liver, and kidney disease. Oral exposures in experimental animals resulted in minor liver impacts in rats.	USEPA Group B2 - Probable human carcinogen. Found to produce liver cancer in mice. Inhalation studies with rats have yielded evidence of carcinogenicity (leukemia). No epidemiological studies conclusively linking human exposure to carcinogenicity.	Animal studies suggest potential teratogenic and embryotoxic effects.

SOURCES: Clement 1985  
Beliles 1979  
Wreen 1987

National Institute of Occupational Safety and Health  
U.S. Environmental Protection Agency 1987

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sensitive response in the most sensitive test organism, is used to establish a reference dose (RfD). In assessing risks, it is the most sensitive response which is the determinant of whether exposure is acceptable or not.

Critical toxicity values for the indicator chemicals are listed in Table 5-2. The toxic endpoints for the values listed in Table 5-2 are usually cellular alterations that are reversible or show no effect on total animal function. Additional safety factors are applied to the dose eliciting the most sensitive response. Thus, the RfD is a dose which has not shown an effect in animal or human populations.

Table 5-2. Reference Doses and Potency Factors

Constituent	Oral		Oral	
	RfD (mg/kg/day)	q* (mg/kg/day)	RfD (mg/kg/day)	q* (mg/kg/day)
<b>Inorganics</b>				
Barium	0.051	NA	$1.4 \times 10^{-4}$	NA
Cadmium	0.0005	NA	NA	6.1
Mercury	0.002	NA	$5.1 \times 10^{-5}$	
Nickel	0.01	NA	NA	1.19
Nitrate (as N)	0.28	NA	NA	NA
Uranium	0.002	0.87	0.002	0.87
<b>Organics</b>				
Tetrachloroethene	0.02	0.051	NA	0.0017
Trichloroethene	0.00735	0.011	NA	0.0046

SOURCE: U.S. Environmental Protection Agency 1986b  
 U.S. Environmental Protection Agency 1987a  
 U.S. Environmental Protection Agency 1987b  
 National Academy of Sciences 1984

RfD = Reference Dose  
 q\* = Potency Factor

The critical toxicity endpoints for the indicator chemicals RfDs are:

- ° barium      hypertensinogenic effects in rats, using a safety factor of 100 (Perry et al. 1983);
- ° cadmium    estimate of ingestion rate that will not exceed critical renal concentration after 50 years, using a safety factor of 10 (Friberg et al. 1974);

- mercury      proteinuria and nephrotic syndrome in rats injected subcutaneously with mercuric chloride, using safety factor of 100 (Druet et al. 1978);
- nickel        reduction in body weight of rats given nickel sulfate in diet, using safety factor of 100 (Ambrose et al. 1976);
- nitrate        absence of methemoglobinemia in sensitive infant population with acute diarrhea (Walton 1951);
- uranium      prevention of chronic kidney damage using a safety factor of 50 to 150 (Wrenn et al. 1987);
- PCE           slight increase in liver weight in mice orally dosed using a safety factor of 1000 (Buben and O'Flaherty 1985); and
- TCE           elevated liver weights due to hydropic changes or fatty accumulation in rats dosed by inhalation, using a safety factor of 1000 (Kimmerle and Eben 1973).

Acceptable concentrations in drinking-water based on the RfD or cancer potency factor are listed in Table 5-3. Surface water criteria based on aquatic toxic endpoints are also listed in Table 5-3.

Table 5-3. Applicable or Relevant and Appropriate Requirements for Indicator Chemicals Detected at the S-3 Waste-Management Area

Constituent	Average Ground-Water Concentration	Human		Aquatic Life	
		ARAR	Source	ARAR	Source
Inorganics					
Barium	47	0.050	<i>a</i>	CU	<i>c</i>
Cadmium	0.099	0.010	<i>a</i>	0.0011	<i>d</i>
Mercury	0.0075	0.002	<i>a</i>	0.000012	<i>d</i>
Nickel	2.08	0.0134	<i>b</i>	0.16	<i>d</i>
Nitrate (as N)	2,180	10	<i>a</i>	NA	
Uranium	2.57	NA		NA	
Organics					
Tetrachloroethene	0.271	0.0008	<i>b</i>	0.84	<i>d</i>
Trichloroethene	0.033	0.005	<i>a</i>	21.9	<i>d</i>

NOTE: All concentrations reported in milligrams per liter (mg/L).

SOURCE: *a* USEPA Primary Drinking-Water Standard (40 CFR 141)  
*b* Federal Water Quality Criteria (FWQC for water and fish ingestion, 10<sup>-6</sup> Cancer Risk) (U.S. Environmental Protection Agency 1986a)  
*c* Criteria Unwarranted because barium should precipitate out of solution before toxic concentrations are reached (U.S. Environmental Protection Agency 1986a)  
*d* FWQC for chronic exposure of fresh-water aquatic life (U.S. Environmental Protection Agency 1986a)

### 5.1.2 Carcinogenic Effects

Cancer is considered to be the end result of a multistage process in which a large number of biological and environmental factors interact, simultaneously or in sequence, to disrupt normal cell growth and division. The first stage, termed initiation, involves the formation of errors in genetic coding. Because the effects of initiation are believed to occur at the molecular level, current regulatory policy is based on the concept that there is no finite dose or threshold below which carcinogens will not exert an effect.

Due to the multistage interactive process involved in cancer development, the frequency of carcinogenic effects is very low, especially at chemical concentrations that might occur in the environment. In attempts to increase the sensitivity of carcinogen identification in small animal test populations, very high doses are used in the laboratory to elicit a higher incidence of cancer. From the results of these high-dose animal experiments, an extrapolation is made from the high dose/high incidence laboratory data to a dose associated with a very low hypothetical cancer incidence, such as one additional cancer in an exposed population of one million.

Various mathematical models are available to extrapolate from the high dose to zero dose; however, the U.S. Environmental Protection Agency currently favors a linearized multistage model which provides a 95-percent upper-bound estimate of hypothetical incidence. The slope of this extrapolated curve, termed the "carcinogen potency factor" or "unit cancer risk" is used in calculating the probability of cancer associated with a given dose. The probability is termed the "cancer risk". The potency factors for uranium, PCE and TCE are listed in Table 5-2.

The cancer risk is not an accurate quantification of cancer incidence. Because of the uncertainties associated with high-dose testing, the no-threshold theory, and the conservative nature of the extrapolation model, the cancer risk represents only a rough

estimate of the upper limit of risk. Using the method, it is not likely that the true risk would be more than the estimated risk, but it could be considerably lower (U.S. Environmental Protection Agency, 1986c).

Uranium is not a chemical carcinogen. Ionizing radiation associated with uranium is known to be carcinogenic in humans and animals. On this basis the ionizing radiation associated with uranium could be classified as a Group A Human Carcinogen by the U.S. Environmental Protection Agency. Both PCE and TCE are Group B2 Probable Human Carcinogens, which means that there is sufficient evidence of carcinogenicity in animals, but insufficient evidence of carcinogenicity in humans. While the weight of evidence for the various carcinogens does not influence the U.S. Environmental Protection Agency derived potency factors used in calculating risk, it is an important consideration when evaluating an appropriate level for acceptable carcinogenic risks.

## 5.2 SUMMARY

Two of the eight indicator chemicals are suspect oral chemical carcinogens (PCE and TCE), and one of the indicator chemicals is a potential ionizing radiation carcinogen (uranium). Public and regulatory perception of acceptable exposure to carcinogens is relatively stringent, and this is reflected in the much lower reference standards resulting from carcinogenic endpoint evaluations. The noncarcinogenic critical toxicity endpoints are the most sensitive responses observed in the most sensitive test population. RfDs derived from the critical toxicity endpoints incorporate additional safety factors, and are essentially daily exposure rates for which adverse responses have not been observed. The RfDs and cancer potency factors ( $q^*$ ) for the indicator chemicals are listed in Table 5-2.

## 6.0 RISK CHARACTERIZATION

The risk characterization is based on consideration of the analytical results, potential for exposure, estimates of exposure intake, and the toxicity of the constituents. Absence of an exposed population and/or absence of compounds at concentrations eliciting recognized toxic responses will eliminate the potential risk.

### 6.1 PUBLIC HEALTH

For assessment of human health risks two approaches are used depending on whether the toxic endpoint has a threshold (noncarcinogenic) or no threshold (carcinogenic). Noncarcinogenic hazards are quantified as the ratio of the exposure dose to a verified RfD. The ratio is termed a Hazard Index (HI), and an HI less than one is an indication that exposure levels are below levels that have been associated with any adverse effects. To account for contributions from other sources, it is routinely assumed that only 20% of the acceptable exposure level should be associated with a single exposure pathway. Thus, an HI of 0.2 is generally used as the basis for designating an acceptable level of exposure to noncarcinogens.

Cancer risks are based on extrapolated hypothetical lifetime excess cancer incidences. The slope of the extrapolation curve from the high dose observed laboratory cancer incidences to the extremely low hypothetical incidences is called the cancer potency factor. The cancer risk is the product of the exposure dose multiplied by the potency factor. In general, the U.S. Environmental Protection Agency has made decisions to allow concentrations of carcinogens where the individual cancer risk levels have been in the range of  $10^{-7}$  to  $10^{-4}$  (the possibility that one exposed lifetime cancer incidence may occur in an exposed population of 10,000 to 10,000,000). Risk levels less than  $10^{-7}$  are considered nonquantifiable because the extrapolation models are unreliable at these low incidence

levels. Cancer risk levels greater than  $10^{-4}$  are an indication that exposure levels are probably unacceptable.

Interactions of multiple constituents is not well understood; however, as an effort to compensate for chemical interactions, the U.S. Environmental Protection Agency (1986b) recommends an additive approach. The HI or cancer risk levels are added together, and if the sum total HI is less than one, or if the cancer risk level is within the  $10^{-7}$  to  $10^{-4}$  range, then the exposure levels are considered acceptable. If the HI is greater than one, or the cancer risk level is greater than  $10^{-4}$ , then a closer examination of the toxic effects is warranted to discern if they have a toxic effect in common, and if the additive approach is warranted.

A total site noncarcinogenic HI and total site cancer risk will be used to determine if the combination of all exposure pathways and all constituents would result in the potential for adverse effects. An HI less than 0.2 and cancer risk level in the  $10^{-7}$  to  $10^{-4}$  range are an indication that total site exposure levels are acceptable.

#### 6.1.1 Surface Water

Noncarcinogenic HI for dermal contact and ingestion of waters from Bear Creek and East Fork Poplar Creek are 0.015 and 0.00028, respectively (Table 6-1). Because the HI for both creeks are below 0.2, adverse effects would not be expected from this level of exposure.

Cancer risk levels for the same dermal contact and ingestion exposure to constituents in Bear Creek and East Fork Poplar Creek are  $7.0 \times 10^{-6}$  and  $5.5 \times 10^{-8}$ , respectively (Table 6-2). Cancer risks for both creeks are within the  $10^{-7}$  to  $10^{-4}$  range, and represent acceptable exposure levels. The dominant cancer risk in Bear Creek is associated with the radiation effects of uranium. PCE and TCE risk levels are insignificant,

Table 6-1. Noncarcinogenic Hazard Indices for Constituents Associated with the S-3 Waste-Management Area

Exposure Route	Ba	Cd	Hg	Ni	NO <sub>3</sub>	U	PCE	TCE	Total
Surface Water									
Bear Creek	1.2 x 10 <sup>-5</sup>	5.0 x 10 <sup>-5</sup>	8.5 x 10 <sup>-7</sup>	3.3 x 10 <sup>-6</sup>	1.1 x 10 <sup>-2</sup>	4.0 x 10 <sup>-3</sup>	3.8 x 10 <sup>-6</sup>	1.0 x 10 <sup>-5</sup>	1.5 x 10 <sup>-2</sup>
East Fork Poplar Creek	8.6 x 10 <sup>-6</sup>	2.4 x 10 <sup>-9</sup>	3.4 x 10 <sup>-5</sup>	3.8 x 10 <sup>-6</sup>	1.7 x 10 <sup>-4</sup>	2.9 x 10 <sup>-5</sup>	3.8 x 10 <sup>-6</sup>	1.0 x 10 <sup>-5</sup>	2.8 x 10 <sup>-4</sup>
Sediment									
Bear Creek	—	1.0 x 10 <sup>-3</sup>	3.4 x 10 <sup>-5</sup>	9.4 x 10 <sup>-4</sup>	—	2.2 x 10 <sup>-3</sup>	—	—	4.2 x 10 <sup>-3</sup>
East Fork Poplar Creek	—	3.8 x 10 <sup>-4</sup>	4.1 x 10 <sup>-3</sup>	4.2 x 10 <sup>-4</sup>	—	—	—	—	4.9 x 10 <sup>-3</sup>
Fish									
Bear Creek	—	4.4 x 10 <sup>-3</sup>	2.4 x 10 <sup>-2</sup>	—	—	—	—	—	2.8 x 10 <sup>-2</sup>
East Fork Poplar Creek	—	2.4 x 10 <sup>-3</sup>	6.0 x 10 <sup>-2</sup>	—	—	—	—	—	6.2 x 10 <sup>-2</sup>
Ground Water	7.4 x 10 <sup>-4</sup>	1.6 x 10 <sup>-4</sup>	3.0 x 10 <sup>-6</sup>	1.7 x 10 <sup>-4</sup>	1.2 x 10 <sup>-2</sup>	1.0 x 10 <sup>-3</sup>	2.2 x 10 <sup>-5</sup>	7.2 x 10 <sup>-6</sup>	1.4 x 10 <sup>-2</sup>
All Routes	7.6 x 10 <sup>-4</sup>	8.4 x 10 <sup>-3</sup>	8.8 x 10 <sup>-2</sup>	1.5 x 10 <sup>-3</sup>	2.3 x 10 <sup>-2</sup>	7.2 x 10 <sup>-3</sup>	3.0 x 10 <sup>-5</sup>	2.7 x 10 <sup>-5</sup>	0.13

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as would be expected from the low probability of exposure to these highly volatile constituents in surface waters.

Table 6-2. Total Site Carcinogenic Risk for Constituents Associated with the S-3 Waste-Management Area

Exposure Route	U	PCE	TCE	Total
<b>Surface Water</b>				
Bear Creek	$7.0 \times 10^{-6}$	$3.8 \times 10^{-9}$	$8.2 \times 10^{-10}$	$7.0 \times 10^{-6}$
East Fork Poplar Creek	$5.0 \times 10^{-8}$	$3.8 \times 10^{-9}$	$8.2 \times 10^{-10}$	$5.5 \times 10^{-8}$
<b>Sediment</b>				
Bear Creek	$3.9 \times 10^{-6}$	—	—	$3.9 \times 10^{-6}$
East Fork Poplar Creek	—	—	—	—
<b>Fish</b>				
Bear Creek	—	—	—	—
East Fork Poplar Creek	—	—	—	—
<b>Ground Water</b>	$1.7 \times 10^{-6}$	$2.2 \times 10^{-8}$	$5.8 \times 10^{-10}$	$1.7 \times 10^{-6}$
<b>All Routes</b>	$1.3 \times 10^{-5}$	$3.0 \times 10^{-8}$	$2.2 \times 10^{-9}$	$1.3 \times 10^{-5}$

Bear Creek and East Fork Poplar Creek do not present a hazard to researchers accessing the creeks. Because exposure frequency and potential constituent concentrations exposed to are would be highest for a hypothetical researcher accessing the headwaters of the creeks, exposure levels and associated hazards for other populations accessing the creeks will be lower.

#### 6.1.2 Sediments

Noncarcinogenic HI for dermal contact and ingestion of sediments from Bear Creek and East Fork Poplar Creek are 0.0042 and 0.0049, respectively (Table-6-1). Because the HI for both creeks are below 0.2, adverse effects would not be expected from this level of exposure.



Cancer risk levels for the same dermal contact and ingestion exposure to constituents in Bear Creek sediments are  $3.9 \times 10^{-6}$  (Table 6-2). There is no cancer risk level for East Fork Poplar Creek because there were no reported concentrations of uranium, PCE or TCE in the creek. Cancer risks for Bear Creek are within the  $10^{-7}$  to  $10^{-4}$  range, and represent acceptable exposure levels. Uranium is the only potentially carcinogenic constituent considered in the assessment. PCE and TCE risk levels are insignificant, as would be expected from the low probability of exposure to these highly volatile constituents in sediments.

Potential exposure to sediments in Bear Creek and East Fork Poplar Creek will not result in any known adverse effects to researchers accessing the creeks. Potential hazards to other populations exposed to the sediments will be even lower because of the lower frequency and concentration at the potential exposure point.

#### 6.1.3 Fish

Noncarcinogenic HI for ingestion of fish caught in Bear Creek and East Fork Poplar Creek are 0.028 and 0.062, respectively (Table 6-1). HI for both creeks are below 0.2, thus, adverse effects would not be expected from this level of exposure. These HI are based on actual fish sample concentrations, rather than theoretical calculated concentrations, and are considered a good estimate of potential hazards associated with ingestion of fish caught just beyond the boundaries of the DOE reservation.

There are no identifiable cancer risk levels associated with fish ingestion, because there were no reported concentrations of carcinogenic compounds in the fish that might be associated with constituents released from the S-3 WMA.

Potential exposure levels and hazards associated with ingestion of fish from Bear Creek and East Fork Poplar Creek are acceptable for the constituents potentially seeping into the creeks from ground water impacted by the S-3 WMA.

#### 6.1.4 Ground Water

The noncarcinogenic HI for dermal contact and ingestion of ground water from monitor wells during sample collection is 0.014 (Table 6-1). HI for exposure to the ground water is below 0.2; thus, adverse effects would not be expected from this level of exposure.

Cancer risk levels for the same dermal contact and ingestion exposure to the ground water during monitoring is  $1.7 \times 10^{-6}$  (Table 6-2). Cancer risk levels are within the  $10^{-7}$  to  $10^{-4}$  range and represent acceptable exposure levels. Potential cancer risks associated with the radiological effects of uranium are the dominant cancer risk in the ground water. PCE and TCE cancer risk levels are approximately two orders of magnitude or more lower than uranium and are an insignificant contribution to the total ground water cancer risk level.

Potential exposure of investigators or contractors collecting ground water samples from the plume are not expected to result in adverse effects. Exposure of researchers at the lysimeter study area is also assumed to be acceptable because the level and frequency of exposure is expected to be lower.

#### 6.1.5 Total Site Risks

The total noncarcinogenic site risk for exposure to the reported concentrations of the indicator chemicals via surface water, sediment, fish and ground water is 0.13 (Table 6-1). This HI is less than 0.2, thus, adverse effects are not expected, and exposure levels associated with constituents from the S-3 WMA are acceptable.

The total site cancer risk is  $1.3 \times 10^{-5}$  (Table 6-2). This cancer risk is within the  $10^{-7}$  to  $10^{-4}$  range, and is considered potentially acceptable. Exposure to constituents by all identified pathways does not result in an unacceptable level of cancer risk.

## 6.2 ENVIRONMENTAL RISKS

Potential environmental exposure to constituents released from the S-3 WMA is primarily limited to Bear Creek and East Fork Poplar Creek waters and sediments. As summarized in Table 4-2, surficial soils and the atmosphere are not a source of contaminants, and release to these media is insignificant compared with release to the surface waters. Bear Creek and East Fork Poplar Creek are the only identified discharge points for the contaminant plumes; therefore, these creeks are the exposure points for the terrestrial and aquatic ecosystems.

### 6.2.1 Terrestrial Impact Assessment

Exposure of the terrestrial ecosystem is dependent on the usage of the creeks as a source of drinking water or food for the wildlife. Mammals and birds drinking the creek water or eating fish or plants from the stretches of the creeks impacted by the S-3 WMA will be exposed to the constituents. Data on the number of species, population density, and frequency and pattern of creek usage are not known; however, based on the quality of Bear Creek water during the period when the S-3 Ponds were utilized and changes in the Y-12 Plant waste water discharge practices to East Fork Poplar Creek, the short-term historical usage of the creeks is assumed to have been minimal. Improving water quality in both creeks will probably result in increasing usage by terrestrial organisms, as compared with usage patterns in the past 20 years. However, the initial headwaters area of East Fork Poplar Creek is still within the highly developed portion of the Y-12 Plant, therefore, it is unlikely that significant increases in usage of this stretch of creek can be expected. Thus,

as the concentrations of constituents in Bear Creek decreases, the level of usage by terrestrial organisms is expected to increase.

Bioconcentration potential is relatively low for barium, cadmium, nickel, PCE, and TCE. Bioconcentration factors (BCF) for these constituents are as follows:

barium	<100 L/kg
cadmium	81 L/kg
nickel	47 L/kg
PCE	31 L/kg
TCE	11 L/kg

A BCF less than 100 L/kg is generally considered low. Nitrate is reported to show no evidence of bioaccumulation in any storage tissues (U.S. Environmental Protection Agency 1987c). Uranium has a slightly higher bioaccumulation potential with a BCF of 330 in algae. This potential is still relatively low when compared with the BCF reported in the literature for inorganic mercury of 5500 (U.S. Environmental Protection Agency, 1986b). However, if the maximum concentration of mercury detected in fish collected from Bear Creek (0.56 mg/kg) and East Fork Poplar Creek (1.4 mg/kg) is compared with the average mercury concentrations in Bear Creek (0.0004 mg/L) and East Fork Poplar Creek (0.0041 mg/L), then the BCF for mercury from the creeks ranges from 340 to 1400. This is still higher than the other constituents but significantly lower than the level reported in the literature. Of the eight indicator chemicals, mercury has the greatest potential for bioaccumulation and food chain magnification.

Mercury reported in East Fork Poplar Creek sediments and water are associated with past Y-12 Plant practices which discharged mercury in wastewater, and from spills at areas unrelated to the S-3 WMA. Mercury detected in the ground water is not highly mobile; therefore, the rate of mercury seepage to either Bear Creek or East Fork Poplar

Creek is low. Potential exposure levels and risks to terrestrial organisms from the low concentrations of mercury potentially seeping to the creeks are low. Potential exposure to the headwaters area of East Fork Poplar Creek, where the highest concentrations of mercury are located is unlikely for terrestrial organisms. Thus, mercury from the S-3 WMA is not considered a threat to the terrestrial ecosystem.

#### 6.2.2 Aquatic Impact Assessment

Bear Creek and East Fork Poplar Creek are identified as the discharge points for the contaminant plume reported in the ground water. Bear Creek had been severely stressed during the period when the S-3 Ponds were in operation. In 1975, seepage from the S-3 Ponds created an acutely toxic environment for a distance of at least 1.24 mi (from the S-3 Site to below the Sanitary Landfill/Oil Landfarm area), characterized by low pH and high levels of many trace elements (Loar, et al. 1985). Neutralization of the S-3 Ponds, termination of all discharges to the ponds, and denitrification of the ponds resulted in a recovery by 1984. The zone of high toxicity was reduced from more than 1.24 mi to less than 0.62 mi. Presently, the zone of high toxicity has been eliminated.

A diverse and abundant fish community inhabits the reach of Bear Creek adjacent to the Burial Grounds and Sanitary Landfill/Oil Landfarm (Loar et al. 1985). Unlike the fish communities, where impacts are identified only in the extreme upper reaches of Bear Creek, the benthic invertebrate communities are impacted over a much greater reach of the creek. In stream contamination, both turbidity and potentially toxic substances in sediments, have been identified as threats to fish and benthic invertebrates in Bear Creek and both decrease with increasing distance downstream from the S-3 WMA.

Using the U.S. Environmental Protection Agency Federal Water Quality Criteria (FWQC) as a gauge of potential acceptable creek concentrations, barium, nickel, uranium, PCE, TCE, and possibly cadmium have a low potential for adverse effects to the aquatic

ecosystem (Table 6-3). Maximum cadmium concentrations in Bear Creek exceeded the FWQC, but cadmium detection limits for the average concentrations were higher than the FWQC, therefore it is uncertain whether average cadmium concentrations are a potential hazard. Concentrations of mercury (primarily in East Fork Poplar Creek) and nitrate (primarily in Bear Creek) exceed the FWQC or concentrations believed to be acceptable for freshwater aquatic organisms.

Table 6-3. Concentration Detected in Bear Creek and East Fork Poplar Creek Waters and Associated Aquatic Criteria

Constituent	Bear Creek <sup>a</sup>	East Fork Poplar Creek <sup>a</sup>	FWQC <sup>b</sup>
Barium	0.076	0.053	50 <sup>c</sup>
Cadmium	0.006 <i>d</i>	0.003 <i>d</i>	0.0011
Mercury	0.0004 <i>d</i>	0.008	0.000012
Nickel	0.003 <i>d</i>	0.009 <i>d</i>	0.16
Nitrate (as N)	198	3.1	90 <sup>e</sup>
Uranium	0.969	0.007	1.0 <sup>f</sup>
Tetrachloroethene	0.01 <i>d</i>	0.01 <i>d</i>	0.84
Trichloroethene	0.01 <i>d</i>	0.01 <i>d</i>	21.9

NOTE: All concentrations reported in milligrams per liter (mg/L).

<sup>a</sup> Average concentrations reported in weekly water samples (Martin Marietta Energy Systems 1988).

<sup>b</sup> Federal Water-Quality Criteria for freshwater aquatic life (U.S. Environmental Protection Agency 1986a).

<sup>c</sup> Criteria considered unwarranted because barium usually precipitates out of solution at concentration below 50 mg/L to nontoxic precipitates.

<sup>d</sup> Constituent was undetected at this concentration.

<sup>e</sup> No FWQC established; Level is estimate of concentration that will not result in adverse effects to warm water fish (U.S. Environmental Protection Agency 1986a).

<sup>f</sup> No FWQC established; Level is lower estimate of concentration range that was not toxic to invertebrate populations (Stewart 1987).

Average mercury concentrations in East Fork Poplar Creek are more than 2 orders of magnitude higher than the FWQC. Chronic toxicity was observed in the freshwater invertebrate Daphnia magna at concentrations as low as 0.0011 mg/L, and chronic toxicity for the fathead minnow was observed at concentrations as low as 0.00026 mg/L (U.S. Environmental Protection Agency, 1985). Elevated concentrations of mercury in the sediments of East Fork Poplar Creek are the primary source of loading of mercury to the

water (Tennessee Valley Authority, 1986), not the seepage of mercury from the ground water impacted by the S-3 WMA.

It is possible that insignificant amounts of mercury are migrating to East Fork Poplar Creek in the ground water, but this needs additional data to verify. At this time, it can only be concluded that the concentration of mercury in East Fork Poplar Creek is a potential hazard to the aquatic ecosystem.

Concentrations of nitrate in Bear Creek are higher than the recommended concentration of 90 mg/L by less than an order of magnitude. Elevated levels of nitrate are often associated with algal blooms when sufficient phosphate is also present. The algal bloom may result in oxygen depletion in the water body; however, the bloom is usually dependent on the phosphate supply which is the limiting nutrient. Moving waters are not susceptible to oxygen depletion and algal buildup. The 90 mg/L recommended concentration is based on observed decreases in growth and feeding activity in the catfish Ictalurus punctatus. Average concentrations in Bear Creek are approximately twice the recommended concentration, but maximum concentrations have been reported as high as 600 mg/L. Thus, there is a potential for adverse effects on the aquatic ecosystem from nitrate in Bear Creek.

There is a potential for adverse effects to the aquatic ecosystems of Bear Creek and East Fork Poplar Creek, primarily associated with nitrate and mercury. The benthic organisms of Bear Creek have not recovered as completely as the fish, and it may be that the benthic organisms are more susceptible to the constituents entering Bear Creek from the S-3 WMA plumes. Cadmium may also be a potential hazard in Bear Creek because the maximum reported concentration exceeded the FWQC; however, the average concentrations may not present a hazard. The points of environmental exposure closest to the S-3 WMA on Bear Creek and East Fork Poplar Creek are shown in Figure 4-1.

### 6.3 UNCERTAINTIES IN THE RISK EVALUATION

The procedures and inputs used to assess potential human health and environmental risks in this and most such evaluations are subject to a wide variety of uncertainties. In general, there are four main sources of uncertainty.

- Sampling and analysis;
- Fate and transport estimation;
- Exposure estimation; and
- Toxicological data and dose-response extrapolations.

Errors associated with sampling and analysis include the inherent errors in the analysis, representativeness of the samples, sampling errors, and heterogeneity of the sample matrix. While the quality assurance/quality control programs used in the investigations serve to reduce these errors, they can not eliminate all errors associated with sampling and analysis.

This assessment made simplifying assumptions about the environmental fate and transport of constituents. The choice of average concentrations from recent sampling rounds to represent exposure point concentrations is an additional source of potential error.

The estimation of exposure required numerous assumptions to describe potential exposure situations. There are a number of uncertainties regarding the likelihood of exposure, frequency of contact with impacted media, the constituent concentrations at exposure points, and the duration of exposure. These tend to simplify and approximate actual site conditions. Hypothetical worst-case exposure assumptions were used so that potential approximation errors are on the side of safety.



Toxicological data errors are probably the largest source of uncertainty. As the U.S. Environmental Protection Agency noted in its guidelines for carcinogenic risk assessment (U.S. Environmental Protection Agency, 1986c):

"There are major uncertainties in extrapolating both from animals to humans and from high to low doses. There are important species differences in uptake, metabolism, and organ distribution of carcinogens, as well as species and strain differences in target site susceptibility. Human populations are variable with respect to geometric constitution, diet, occupational and home environment, activity patterns, and other cultural factors."

There are inherent uncertainties determining the exposure dose levels that will be combined with toxicological information to assess risk.

This risk assessment used specific assumptions and standardized values. The major assumptions used in this assessment are:

- Constituent concentrations remain constant over the exposure period;
- Exposure remains constant over time;
- Average concentrations of all constituents detected are reasonable estimators of exposure at an exposure point;
- Exposed populations remain constant over the exposure period; and
- Risks are additive.

## 6.4 SUMMARY

Potential exposure dose levels were evaluated relative to the RfDs and excess lifetime cancer risks. Exposure via contact with waters of Bear Creek and East Fork Poplar Creek, contact with the ground water, and ingestion of fish from the two creeks all resulted in exposure dose levels that were within acceptable guidelines in terms of noncarcinogenic and carcinogenic responses. Summation of all the exposure pathways into a total site risk also resulted in a total HI and cancer risk within acceptable guidelines. The overall human

exposure levels to constituents released from the S-3 WMA are acceptable by current regulatory policy.

Potential hazards to the aquatic ecosystem were identified for both Bear Creek and East Fork Poplar Creek. The principal constituent of concern in Bear Creek is nitrate, and the principal constituent of concern in East Fork Poplar is mercury. Although creek conditions have improved since the neutralization of the S-3 Ponds Hazardous Waste Disposal Unit, the concentrations of metals and nitrate discharging from the ground water are an existing and potential future concern.

## 7.0 CONCLUSIONS

Bear Creek and East Fork Poplar Creek are the primary points of potential exposure to constituents released from the S-3 WMA. Ground water beneath the S-3 WMA and area extending along Bear Creek Valley and toward the Y-12 Plant is the principal source of constituents. Discharge of the impacted ground water is to either the headwaters of Bear Creek or to the headwaters of East Fork Poplar Creek. There are no potable wells located on the DOE reservation, or within 3.1 mi of the S-3 WMA off-site, that might possibly be affected by the constituent plumes. Future installation of wells within the area potentially affected by the plumes is extremely unlikely because of the high degree of institutional control that can be exercised on a facility the size of the Oak Ridge Reservation.

Potential exposure to constituents released to Bear Creek and East Fork Poplar Creek were quantified and the associated level of potential hazards are potentially acceptable. Total noncarcinogenic hazard was less than 0.2, and the total cancer risk level was within the  $10^{-7}$  to  $10^{-4}$  range. These levels are generally considered to represent potentially acceptable exposure levels. No unacceptable exposure pathways for human exposure could be identified.

Potential hazards for the aquatic ecosystem were identified to be associated with the concentrations of mercury in East Fork Poplar Creek and the concentrations of nitrate and possibly cadmium in Bear Creek. Although, conditions in the creeks have improved significantly from conditions less than 10 years previous, there remains a potential for adverse effects upon the aquatic community from the concentrations of metals discharging from the ground water to the creeks.

Overall, the S-3 WMA currently presents a low level of potential exposure and hazard to the public, but a moderate level of continued hazard to the aquatic communities of Bear Creek and East Fork Poplar Creek.

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**Appendix A**  
**Exposure Dose Equations and Example Calculations**

**Table A-1. Surface-Water Exposure Dose Equation and Example Calculation**

Equation A.1. Equation Definition

$$SWE = \frac{C_{SW} \times (SSA \times WF \times AF \times ED \times UC + IR) \times EF}{BW \times LFT}$$

WHERE:

SWE = Surface-Water Exposure Dose (mg/kg/day)  
 C<sub>SW</sub> = Surface-Water Concentration (mg/L)  
 SSA = Skin Surface Area of legs and arms (10,260 cm<sup>2</sup>) (USEPA 1984)  
 WF = Water Flux across skin (0.5 mg/cm<sup>2</sup>-hr) (USEPA 1984)  
 AF = Absorption Factor (0.12 inorganics; 1.0 organics and nitrate)  
 ED = Exposure Duration (2.0 hrs/day)  
 IR = Ingestion Rate (0.01 L/day)  
 UC = Unit Conversion (10<sup>-6</sup> L/mg)  
 EF = Exposure Frequency (1,300 days/lifetime) (260 day/month for 5 years)  
 BW = Body Weight (70 kg) (USEPA 1987a)  
 LFT = Lifetime (2.50x10<sup>4</sup> days/lifetime) (USEPA 1987a)

Equation A.1.1. Equation Example (Barium)

$$SWE = \frac{0.076 \text{ mg/L} \times (10260 \text{ cm}^2 \times 0.5 \text{ mg/cm}^2 \text{-hr} \times 0.12 \times 2.0 \text{ hr/day} \times 10^{-6} \text{ L/mg} + 0.01 \text{ L/day}) \times 1300 \text{ days/lifetime}}{70 \text{ kg} \times 2.50 \times 10^4 \text{ days/lifetime}}$$

$$SWE = 6.3 \times 10^{-7} \text{ mg/kg/day}$$

**Table A-2. Sediment Exposure Dose Equation and Example Calculation**

Equation A.2. Equation Definition

$$SE = \frac{C_S \times (SSA \times DA \times AF \times M + IR) \times EF}{BW \times LFT}$$

WHERE:

SE = Sediment Exposure Dose (mg/kg/day)  
 C<sub>S</sub> = Sediment Weight Fraction (mg/mg)  
 SSA = Skin Surface Area of hands and soles of feet (1,740 cm<sup>2</sup>) (USEPA 1984)  
 DA = Dust Adherence (1.45 mg/cm<sup>2</sup>-day) (USEPA 1984)  
 AF = Absorption Factor (0.12 inorganics; 1.0 organics and nitrate)  
 M = Media Absorption Influence (0.15 for soils)  
 IR = Ingestion Rate (100 mg/day) (USEPA 1984)  
 EF = Exposure Frequency (1,300 days/lifetime) (260 days/year for 5 years)  
 BW = Body Weight (70 kg) (USEPA 1987a)  
 LFT = Lifetime (2.50 x 10<sup>4</sup> days/lifetime) (USEPA 1987a)

Equation A.2.1. Equation Example (Cadmium)

$$SE = \frac{4.5 \times 10^{-6} \text{ mg/mg} (1740 \text{ cm}^2 \times 1.45 \text{ mg/cm}^2 \text{-day} \times 0.12 \times 0.15 + 100 \text{ mg/day}) \times 1300 \text{ days/lifetime}}{70 \text{ kg} \times 2.50 \times 10^4 \text{ days/lifetime}}$$

$$SE = 5.0 \times 10^{-7} \text{ mg/kg/day}$$

**Table A-3. Ground-Water Exposure Dose Equation and Example Calculation**

Equation A.3. Equation Definition

$$GWE = \frac{C_{GW} \times (SSA \times WF \times AF \times ED \times UC + IR) \times EF}{BW \times LFT}$$

WHERE:

GWE = Ground-Water Exposure Dose (mg/kg/day)  
 CGW = Ground-Water Concentration (mg/L)  
 SSA = Skin Surface Area of hands and arms (3,420 cm<sup>2</sup>) (USEPA 1984)  
 WF = Water Flux across skin (0.5 mg/cm<sup>2</sup>-hr) (USEPA 1984)  
 AF = Absorption Factor (0.12 inorganics; 1.0 organics and nitrate)  
 ED = Exposure Duration (8.0 hrs/day)  
 IR = Ingestion Rate (0.01 L/day) (USEPA 1987a)  
 UC = Unit Conversion (10<sup>-6</sup> L/mg)  
 EF = Exposure Frequency (120 days/lifetime) (1 day/month for 10 years)  
 BW = Body Weight (70 kg) (USEPA 1987a)  
 LFT = Lifetime (2.50x10<sup>4</sup> days/lifetime) (USEPA 1987a)

Equation A.3.1. Equation Example (Barium)

$$GWE = \frac{47 \text{ mg/L} \times (3420 \text{ cm}^2 \times 0.5 \text{ mg/cm}^2 \text{-hr} \times 0.12 \times 8 \text{ hr/day} \times 10^{-6} \text{ L/mg} + 0.01 \text{ L/day}) \times 120 \text{ days/lifetime}}{70 \text{ kg} \times 2.50 \times 10^4 \text{ days/lifetime}}$$

$$GWE = 3.8 \times 10^{-5} \text{ mg/kg/day}$$

**Table A-4. Fish Ingestion Exposure Dose Equation and Example Calculation**

Equation A.4. Equation Definition

$$FE = \frac{C_F \times IR \times EF}{BW \times LFT}$$

WHERE:

FE = Fish Exposure Dose (mg/kg/day)  
 CF = Concentration in fish tissue (mg/mg)<sup>a</sup>  
 IR = Ingestion Rate (0.006 kg/day) (USEPA 1984)  
 EF = Exposure Frequency ( )  
 BW = Body Weight (70 kg) (USEPA 1987a)  
 LFT = Lifetime (2.50 x 10<sup>4</sup> days/lifetime) (USEPA 1987a)

Equation A.4.1. Equation Example (Cadmium)

$$FE = \frac{0.026 \text{ mg/kg} \times 0.006 \text{ kg/day} \times 2.50 \times 10^4 \text{ days/lifetime}}{70 \text{ kg} \times 2.50 \times 10^4 \text{ days/lifetime}}$$

$$FE = 2.2 \times 10^{-6} \text{ mg/kg/day}$$

<sup>a</sup> fish tissue concentrations (mg/kg) (TLV 1986)

R12-27-88Ba

	Bear Creek	East Fork Poplar Creek
Cadmium (fish)	0.026	0.014
Cadmium (crayfish)	1.500	0.780
Mercury (fish)	0.560	1.400
Mercury (crayfish)	—	0.810

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